2020-06

Effectiveness of pesticidal plant extracts on field and post-harvest pests in Bambara groundnuts in Tanzania

Tlankka, Nicodemus Sakweli

NM-AIST

EFFECTIVENESS OF PESTICIDAL PLANT EXTRACTS ON FIELD AND POST-HARVEST PESTS IN BAMBARA GROUNDNUTS IN TANZANIA

Nicodemus Sakweli Tlankka

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

June, 2020

ABSTRACT

A randomized complete block design (RCBD) experiment was conducted to assess the effectiveness of *Bidens pilosa, Lantana camara, Vernonia amygdalina, Tithonia diversifolia, Tephrosia vogelii* and *Lippia javanica* against field pests of bambara groundnuts. The extracts were prepared by dissolving powder of the plants leaves at the concentration of 10% (w/v) in tap water containing 1% soap and left for 24 hours. Then, extracts were sprayed on 2 weeks seedlings of bambara groundnut and assessment of the abundance of insect pests and beneficial arthropods and plant damage was conducted weekly for 15 weeks. The results showed that pesticidal plants significantly ($P \leq 0.05$) reduced the abundance of foliage beetles, aphids, mealybugs, red spider mites, and leafhoppers and caused significantly ($P \leq 0.05$) less threat to ladybird, hoverfly, wasps and spiders. A storage experiment was conducted to assess the insecticidal effectiveness of *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica*, *T. diversifolia* and *Croton dichogamus* leaves powder on *Callosobruchus maculatus*. The pesticidal plants powder were admixed with grains at the dosage of 10% (w/w) and compared with actellic dust and untreated control. The experiment was monitored for 6 months. *T. vogelii* and actellic dust were the most effective treatments by killing 93.07 - 100% and 91.33 - 100% of bruchids respectively for 180 days of the study. Therefore, *Tephrosia vogelii* is recommended in controlling field and post-harvest pests in bambara groundnuts. Further research is recommended to assess the active compounds, mode of action and toxicity of *T. vogelii* and assess its effect on non-target organisms in bambara groundnuts.

DECLARATION

I, Nicodemus Sakweli Tlankka, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

11. 06. 2020

Nicodemus S. Tlankka
Name and signature of candidate

Date

The above declaration is confirmed;

11. 06. 2020

Prof. Patrick A. Ndakidemi
Name and signature of supervisor

Date

11. 06. 2020

Prof. Steven Belmain
Name and signature of supervisor

Date

11. 06. 2020

Dr. Ernest R. Mbega
Name and signature of supervisor

Date

COPYRIGHT

CERTIFICATION

The undersigned certify that they have read the dissertation titled "Effectiveness of Pesticidal Plant Extracts on Field and Post-Harvest Pests in Bambara Groundnuts in Tanzania" and recommend for examination in the fulfillment of the requirements for the degree of Masters in Life Sciences with specialization in Sustainable Agriculture of the Nelson Mandela African Institution of Science and Technology.

Prof. Patrick A. Ndakidemi | 11-06-2020
Name and signature of supervisor | **Date**

Prof. Steven Belmain | 11.06.2020
Name and signature of supervisor | **Date**

Dr. Ernest R. Mbega | 11.06.2020
Name and signature of supervisor | **Date**

ACKNOWLEDGEMENT

Thanks to God, the Almighty for His guidance and protection throughout my studies. Sincerely, I would like to thank the Nelson Mandela African Institution of Science and Technology for rendering me admission, the Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security (CREATES, FNS) for sponsoring my studies. Thanks to the McKnight Foundation for additional funding for my research through the grant from Bill and Melinda Gates Foundation given to The Nelson Mandela African Institution of Science and Technology.

I would like to give many thanks to my supervisors Prof. Patrick A. Ndakidemi, Dr. Ernest R. Mbega (NM-ASIT) and Prof. Steven Belmain (the Natural Resource Institute, University of Greenwich) for their tireless guidance, advice and support to me towards a successful completion of my research work.

Lastly, I would like to express regards to my parents and the entire family members for the prayers, love, encouragement and support that made me complete my studies successfully.

DEDICATION

This dissertation is dedicated to my lovely kids Goodluck and Kendrick and whole family for their love, support, encouragement and prayers that made me perform my studies. It is my prayers that the Almighty God grants you many years of success as you grow up.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS AND SYMBOLS

%	Percentage
≤	Less or equal
°C	Degrees centigrade
ANOVA	Analysis of Variance
CREATES, FNS	Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security
DAFF	Department of Agriculture, Fisheries and Forestry
FAO	Food and Agriculture Organization
Ha	Hectare
KG	Kilogram
LSD	Least Significance Difference
M	Meter
MR	Mortality rate
NARI	Naliendele Research Institute
NM-AIST	Nelson Mandela African Institution of Science and Technology
P	Probability
RCBD	Randomized Complete Block Design
RH	Relative humidity
SE	Standard error
TARI	Tanzania Agricultural Research Institute
TPRI	Tropical Pesticides Research Institute

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an important leguminous crop indigenous in Africa (Atiku *et al.*, 2004; Mpotokwane *et al.*, 2008). In many parts of Africa, bambara is ranked the third after peanut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) in terms of consumption and socio-economic importance (Azam *et al.*, 2001; Massawe *et al.*, 2005; Temegne *et al.*, 2018). The grains of bambara groundnuts are highly nutritious containing approximately 15 - 25% protein, 49 - 63.5% carbohydrate, 4.5 - 7.4% fat, 5.2 - 6.4% fiber and 2% mineral (Halimi *et al.*, 2018; Murevanhema & Jideani, 2013). Bambara groundnut is mainly produced for consumption and it serves as a food security crop, eaten as freshly cooked pods or as dry grains combined with main dishes such as cooked plantains and cereals (Heller *et al.*, 1997). Bambara groundnuts serve as a source of income among smallholder farmers especially when the yields of other crops are low due to the prevailing drought and extreme temperatures and crop residues are used to feed livestock (Hillocks *et al.*, 2012; Mayes *et al.*, 2019; William *et al.*, 2016). Being are highly tolerant to tolerant drought and high temperature, bambara groundnut has become a suitable crop for marginal lands (Adeleke *et al.*, 2018; Baryeh, 2001; Hillocks *et al.*, 2012; Mubaiwa *et al.*, 2018; Temegne *et al.*, 2018). Moreover, being a leguminous crop, bambara groundnuts have the ability to fix soil nitrogen of about 20-100 kg ha $^{-1}$ to the soil useful in crop rotations and intercropping with non-nitrogen fixing crops Hillocks *et al*. (2012). Although bambara groundnut has remained underutilized and under-researched for so long (Hillocks *et al.*, 2012) currently, it has attracted research attention and cultivation by farmers mainly due to its climate resilience, unlike other legumes that are at risk due to climate change effects (Mayes *et al.*, 2019; Mkandawire, 2007).

The world production of bambara groundnut in 2016 was estimated by FAO to be 164 589 tonnes whereby the main production is from African countries such as Mali, Cameroon, Niger, Burkina Faso and Democratic Republic of Congo (DRC) (FAO, 2018). In Tanzania, bambara groundnuts are cultivated in Kagera, Mara, Mwanza, Shinyanga, Tabora, Singida, Dodoma, Rukwa, Iringa, Lindi, Ruvuma and Mtwara regions (Heller *et al.*, 1997). However, in Tanzania, the yield of bambara groundnut is 500 - 800 kg ha^{-1} which is lower than the potential yield of 1 500 – 2 000 kg ha^{-1} under proper crop management (NARI, 2015). Low production of bambara in Tanzania is attributed by many factors one of which is attack by insect pests such as aphids (*Aphids sp.*), leafhoppers (*Hilda patruelis*), foliage beetles (*Ootheca mutabilis*), groundnut jassid (*Empoasca facialis*) (DAFF, 2016), red spider mites (*Tetrunychus sp.*) (Collinson *et al.*, 1996), pod sucking bugs (*Clavigralla tomentosicollis* Stäl) (Dike, 1997) and bruchids (*Callosobruchus maculatus* and *C. subinnotatus*) (Mkandawire, 2007).

In an attempt to control pests in the crops, smallholder farmers apply synthetic pesticides as the major insect pests control strategy (Cooper & Dobson, 2007; Weinberger & Srinivasan, 2009). Although the synthetic insecticide has always provided effective control of insect pests, their use are associated with detrimental effects on the health of the pesticide applicators, consumers and is not environmental benign (Aktar *et al.*, 2009; Bag, 2000; Gilden *et al.*, 2010; Lozowicka *et al.*, 2014). The undesirable impacts of synthetic pesticides have raised global concern calling for research on plants with pesticidal effects on insect pests. The use of pesticidal plants is a promising tool for insect pests control hence reducing dependence on synthetic pesticides. Several studies showed that the pesticidal plant extracts are arguably effective control of insect pests on crops (Chikukura *et al.*, 2011; Chougourou *et al.*, 2016; Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Mpumi *et al.*, 2016; Stevenson *et al.*, 2017; Tembo *et al.*, 2018). Pesticidal plants are easily available, less costly and degradable in the environment and less toxic to human and non-targeted organisms (Mkenda *et al.*, 2015a). However, there is limited information regarding to the use of pesticidal plants on the control of pre-harvest and post-harvest insects of bambara groundnuts. Therefore, the present study evaluated the effectiveness of the *Bidens pilosa, Lantana camara, Tephrosia vogelii, Vernonia amygdalina, Lippia javanica* and *Tithonia diversifolia* extracts against pre-harvest pests and dry powder on the post-harvest insects, on bambara groundnut in Tanzania.

1.2 Statement of the problem

Arthropod pests are one of the major constraints to bambara groundnuts production worldwide. For example, in countries such as Nigeria, a yield loss ranging from 43 – 71 % has been reported (Dike, 1997). As in Nigeria, Tanzania's bambara production farmers face similar pest challenges, however, little or no literature exist on for instance types of pests and possible sustainable ecofriendly pest management techniques. Nevertheless, farmers do attempt to control pests with synthetic pesticides regardless of crops (Cooper & Dobson, 2007; Muthomi *et al.*, 2008). Use of synthetic pesticides have been claimed to effectively control insects pests in crops however, their uses are associated with detrimental health effects to the farmers, consumers of the crops produced and the non - target organisms (Aktar *et al.*, 2009; Gilden *et al.*, 2010). These constraints necessitate searching for new approaches that are cheap and eco - friendly such as the use of pesticidal plant extracts as an alternative to synthetic pesticides. Pesticidal plants have been reported to have promising results in controlling insect pests in the field and on storage (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Ogendo *et al.*, 2003b). However, limited information is available on pesticidal plants' effects and effectiveness against in insect pests control on bambara groundnut (as previously described) in the field and on storage. Therefore, the present study aimed at evaluating the effectiveness of the selected pesticidal plant extracts (based on their effects on other crop pests) in the control of field pests and post-harvest insect pest infestation in bambara groundnuts.

1.3 Rationale of the study

Bambara groundnut is an underutilized and under-searched crop. Thus there is limited information on for stance the pests affecting the crop, the magnitude of the damage inflicted by the pests, and the management options including the use of pesticidal plants extracts. Therefore, the present study aimed at evaluating the effectiveness of the selected pesticidal plant extracts in the control of field pests and post-harvest insect pest infestation in bambara groundnuts.

1.4 Objectives of the study

1.4.1 General objective

To evaluate the effectiveness of the pesticidal plant extracts in the control of arthropod pests in the field and post-harvest bruchids infestation in bambara groundnuts.

1.4.2 Specific objectives

(i) To evaluate the effectiveness of crude extracts of *Bidens pilosa, Lantana camara, Tephrosia vogelii, Vernonia amygdalina, Lippia javanica* and *Tithonia diversifolia* on the management of bambara groundnuts arthropod pests and their effects on beneficial insects under field conditions.

(ii) To assess the incidences and severity of different arthropod pest's damage on bambara groundnuts treated with extracts of the pesticidal plants under field conditions.

(iii) To evaluate the effects of the application of the pesticidal plant extracts on yield and yield components of bambara groundnuts.

(iv) To evaluate the effectiveness of powder of pesticidal plants on the management of bruchids (*C. maculatus*) on bambara groundnuts.

1.5 Research questions

(i) What is the effectiveness of crude extracts from *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* on the management of bambara groundnut arthropod pests in field?

(ii) What are the incidences and severity of different arthropod pest's damage on bambara groundnuts under field conditions?

(iii) What are the effects of the application of the pesticidal plant extracts on yield and yield components of bambara groundnuts?

(iv) To what extent does the dry powder from the selected pesticidal plants is effective on management bruchids on bambara groundnuts during storage?

1.6 Significance of the study

The findings of the study provided an understanding of the impact of pesticidal plant extracts for the management of pests on bambara groundnuts in the field and on storage to be used as the alternative of synthetic insecticides. Moreover, they provide useful information and awareness to the smallholder farmers and the society about the cheap, effective and environmentally benign control measures of the arthropod pests affecting the bambara groundnuts on the field and bruchids on stored bambara groundnuts.

1.7 Delineation of the study

This study assessed the effectiveness of crude extracts of selected pesticidal plants on management of field pests and powder on management of storage pests (*Callosobruchus maculatus*) on bambara groundnuts. As such, this study did not aim at competing pesticidal plants with the synthetic pesticides in terms of efficacy, reliability and persistence but rather as inherent agro - ecological intensification (AEI) trade - offs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Key arthropod pests affecting bambara groundnuts

Bambara groundnuts are relatively tolerant to arthropod pests and diseases (Hillocks *et al.*, 2012). However, some literatures have reported that the crop is affected by the wide range of arthropod pests in the field, storage and fungal diseases such as Cercospora leaf spot (*Cercospora* spp.), powdery mildew (*Erysiphe polygoni*) and fusarium wilt (*Fusarium oxypolygoni*) (DAFF, 2016). The arthropod pests affecting the bambara groundnuts including aphids (*Aphis sp.*), leafhopper (*Hilda patruelis*), groundnut jassid (*Empoasca facialis*), and brown leaf beetles (*O. mutabilis*), red spider mites (*Tetrunychus sp.*) (Collinson *et al.*, 1996), pod sucking bugs (*Clavigralla tomentosicollis* Stäl) (Dike, 1997) in the field and bruchids (*C. maculatus and C. subinnotatus*) on the storage (DAFF, 2016; Mkandawire, 2007) are described hereunder.

2.1.1 Aphids (*Aphis spp*.)

Aphids (*Aphis spp*.) (Hemiptera: Aphididae) are small sap-sucking insects widely distributed in Africa. There are about 5000 species of aphids but only 450 species have been recorded on crop plants (Van & Harrington, 2017). Out of 450 species recorded on crop plants, only 100 species that are of agricultural importance (Emden & Harrington, 2017). Bambara groundnut is one of the crop infested by aphids (DAFF, 2016; Mkandawire, 2007). For instance, in Zimbabwe, aphids represent about 65% of the insect pest problem in bambara groundnuts (Heller *et al.*, 1997). Aphids damage plants in all stages of growth from the seedlings stage to flowering (Fig. 1), pod formation and seed filling (Annan *et al.*, 1994). On plant parts such as leaves, stems and pods, aphids form colonies damaging the crops by sucking sap from the plants during feeding or transmitting disease-causing viruses such as rosette virus or through injecting deleterious toxins into the plants (Annan *et al.*, 1994). Heavy aphids infestation on plants, results in wilting and yellowing of the plants or causes plants death to the removal of sap from the plant (Heller *et al.*, 1997). The main aphids control strategies in crops include cultural practices such as early planting, use of resistant varieties (Ofuya, 1997). Other aphids control strategies include physical control and application of chemical insecticides such as phosphamidon, dimethoate, thiometon pirimicarb. The use of synthetic pesticides to control in agriculture is associated with the undesirable effects therefore their use is discouraged

(Ofuya, 1997). The biological control such as the use of natural enemies such as parasitic wasps, hoverfly larvae, lacewings and ladybird beetles which predate on aphids help in suppressing the population of aphids (Emden & Harrington, 2017). Pesticidal plants, on the other hand, have provided promising results in aphid's control in other crops including common beans. For example, Mkindi *et al*. (2017) reported that pesticidal plants such as *B. pilosa*, *L. camara*, *T. vogelii, V. amygdalina*, *L. javanica* and *T. diversifolia* were effective against aphids (*Aphis fabae*) on common beans. However, there is very limited information on the abundance of aphids on bambara groundnuts and the damage caused and use of pesticidal plants in aphids control on bambara groundnuts. Therefore, future research should focus on quantifying the abundance of aphids on bambara groundnuts and the damage caused by them in different cropping systems and to test the effectiveness of the available pesticidal plants to be used as an alternative of synthetic pesticides in Tanzania.

2.1.2 Groundnut leafhopper (*Hilda patruelis* Stal)

The groundnut hopper, *Hilda patruelis* Stal (Homoptera: Tettigometridae) are polyphagous sucking bug widely distributed in Africa (Minja *et al.*, 1999; Rao *et al.*, 2013). Groundnut leafhopper is one of the important insect pests of bambara groundnuts severely affecting their productivity (DAFF, 2016; Uddin *et al.*, 2017). They usually attack plants at the ground and or below the ground level (Minja *et al.*, 1999). During their feeding process, *Hilda* bugs tend to inject toxic saliva on the plants resulting in withering and ultimately dying of the plants. They are usually noticed by the presence of the colonies of black ants which tend to protect them (Minja *et al.*, 1999). The leafhoppers and ants coexist in symbiotic relationship where the leafhoppers produce honey-dew which provide food for the ants while ants protect the leafhoppers against predators (Minja *et al.*, 1999). The adult leafhoppers damage the crop by sucking sap from the stem, pegs and pods resulting in wilting of the plants (Hill, 2008). The affected plants turn yellow, wilt and die due to sap-sucking by the hoppers (Heller *et al.*, 1997; Minja *et al.*, 1999). Although, it is regarded as a minor pest, sporadic infestation during the dry season may lead to significant loss of yield if left uncontrolled (Minja *et al.*, 1999). In Tanzania, there is a lack of information on this insect due to little research attention on bambara groundnuts as it is considered as an under-researched orphan crop (Azam *et al.*, 2001). Therefore, further research should focus on determining the abundance and assessment of the impact of *H. patruelis* on bambara groundnuts grown in different cropping systems and patterns.

2.1.3 Foliage beetles (*Ootheca mutabilis, O. bennigseni*)

Foliage beetles (*O. mutabilis* and *O. bennigseni*) (Coleoptera: Chrysomelidae) are foliage eating insects that are widely distributed in southern and eastern Africa including Tanzania (Abate & Ampofo, 1996). Leaf beetles are important insects affecting, common beans, cowpea and bambara groundnuts (Abate & Ampofo, 1996; DAFF, 2016; Grobbelaar, 2008). The beetles feed on root tissue and seedlings, make holes in the foliage of host plants (Fig. 2) and often feed on blossoms, resulting in crop losses usually when the crop is at the seedling stage. *Ootheca mutabilis and Ootheca bennigseni* are also responsible for transmitting plant viruses (Grobbelaar, 2008). The infestation by foliage beetles is most severe on young plants nonetheless it may persist up to post-flowering. The adult beetles feed on leaves reducing the photosynthetic activity of the plant and may even cause the death of the plants especially if there is a severe attack on the growing points (Abate & Ampofo, 1996). In common beans, the yield losses of 18-31% attributed by foliage beetles in Tanzania have been reported (Abate & Ampofo, 1996). Unfortunately, in Tanzania, there is published information on the magnitude of the impact of this foliage beetles on bambara groundnuts. Therefore, future research is needed to determine the damage inflicted by leaf beetles and evaluate the efficacy of pesticidal plants on control of these insect pests.

2.1.4 Groundnut jassids (*Empoasca fascilis*)

Groundnut jassids *Empoasca fascilis* (Homoptera: Cicadellidae) are small green insects widely distributed in Africa (Rao *et al.*, 2013; Srinivasan, 2014). *Empoasca fascilis* is one of the important insect pests of bambara groundnuts in Africa (DAFF, 2016). The adults and nymphs of jassids pierce and suck on the lower surfaces of the leaf leading to the yellowing of the leaves (Rao *et al.*, 2013). The jassids population growth is generally enhanced by dry and humid conditions. The infestation of many jassids on one leaf may result in yellow spots followed by crinkling, curling, bronzing and drying of the plants (Rao *et al.*, 2013). A yield loss of 3.5 - 39.5% has been reported to be inflicted by jassids in soybeans depending on the susceptibility of the variety (Nasruddin & Gassa, 2014). The management strategies include cultural practices such as intercropping with non - legume crops and use of systemic insecticides. However, the use of synthetic insecticides kills the natural enemies which prey on the adult and nymphs regulating the population of jassids. Thus, future research is needed to look for strategies that have less impact on natural enemies such as the use of extracts from the pesticidal plants.

2.1.5 Pod sucking bugs (*Clavigralla tomentosicollis* Stäl)

Pod sucking bugs, *C. tomentosicollis* Stäl (Hemiptera: Coreidae) are pods sucking bugs predominantly distributed in tropics and sub - tropics of Africa (Srinivasan, 2014). Pod sucking bugs are one of the important pests of bambara groundnuts (Dike, 1997). The nymphs and adults pierce and bugs suck the sap from the young pods leading to the deformation of seeds, necrosis, premature drying of the pods and poor seed formation which ultimately results in low grain yield (Abate & Ampofo, 1996; Srinivasan, 2014). They also feed on stems, leaves and floral buds (Srinivasan, 2014). The insect can cause grain yield loss ranging from 20 - 100% when left uncontrolled on susceptible crops especially during prolonged dry weather (Aliyu *et al.*, 2007). Cultural practices such as intercropping legumes including bambara groundnuts with cereals can reduce the bugs infestation (Srinivasan, 2014). The biological control agents such as the use of *Gryon fulviventris* parasitoid can control *C. tomentosicollis* in Africa (Srinivasan, 2014). On the other hand, synthetic insecticides can also be used to control bugs, however, they may kill even beneficial insects such as parasitoids *G. fulviventris* (Srinivasan, 2014). Pesticidal plants such *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia* on the other hand have provided effective control of insect pests on common beans insect pests including *C. tomentosicollis* (Mkindi *et al.*, 2017). Thus, future research should focus on testing the effectiveness of these pesticidal plants to control pod bugs on bambara groundnuts.

2.1.6 Red spider mites (*Tetrunychus sp.*)

Red spider mites, *Tetrunychus sp.* (Acari: Tetranychidae) are highly polyphagous mites originated in Eurasia but they are now widely distributed worldwide (Raworth *et al.*, 2001). Red spider mites affect a wide range of crops including tomato, cucumber, pepper, rose, strawberry, currant, peach, grapes (Raworth *et al.*, 2001), common beans (Abate & Ampofo, 1996) and bambara groundnuts (Collinson *et al.*, 1996). The damage of crops inflicted by red spider mites depends on the ability of the plant to resist damage. On susceptible crop, spider mites feed on leaves undersides by extracting the plant's sap using their long needle-like mouthparts resulting in the formation of brownish spots and often form webs on plants leaves (Abate & Ampofo, 1996). In severe infestation of mites, the leaves dry and dry off resulting in the wilting of the entire plant (Srinivasan, 2014). The loss of yield of up to 100% has been reported to be caused by spider mites on infested tea (Mamun & Ahmed, 2011) and tomato

(Bagarama, 2016). Unfortunately, there is limited information on damage caused by red spider mites on bambara groundnuts. The infestation of spider mites population is influenced by environmental factors such as low relative humidity, high temperature, drought and long sunshine hours (Ahmed *et al.*, 2012). Bagarama (2016) reported that spider mites are difficult to control. Farmers often use ineffective broad-spectrum synthetic pesticides to control spider mites resulting in pest resistance (Bagarama, 2016). The use of broad-spectrum synthetic pesticides tends to kill the natural enemies which would regulate the population of the spider mites (Srinivasan, 2014). Moreover, predatory mites such as *Phytoseiulus persimilis, Amblyseius womersleyi* and *A. fallacies* (Acari: Phytoseiidae) are effective to control red spider mites under controlled conditions and high relative humidity (Srinivasan, 2014). However, the synthetic insecticides applied also kills beneficial mites. Pesticidal plants, on the other hand, have been reported to reduce spider mites without or with little harm to the natural enemies. For instance, studies by (Muzemu *et al.*, 2011) have revealed pesticidal efficacy of the *L. javanica* and *Solanum delagoense* on red spider mites on rapes and tomatoes (Muzemu *et al.*, 2011). It was found that both *L. javanica* and *S. delagoense* reduced mites by 66.5% and 55% respectively. Despite of the reported effectiveness of, *L. javanica* and *S. delagoense* on spider mites on rapes and tomato, however, there is no published information on their effectiveness on bambara groundnuts spider mites. Thus future research is recommended to investigate the efficacy of indigenous pesticidal plants on bambara groundnut spider mites.

2.1.7 Bruchids, *Callosobruchus maculatus* (F.) and *Callosobruchus subinnotatus* (Pic)

Bruchids, *C. maculatus* and C. *subinnotatus* (Coleoptera: Bruchidae) are serious pests of grain bambara groundnuts in Africa (Ajayi & Lale, 2000; Dike, 1997). *Callosobruchus maculatus* are widely distributed and believed have originated in Africa while *C. subinnotatus* is mainly localized in West Africa (Labeyrie, 2013). These two bruchids species often infest grain bambara groundnuts simultaneously. When these two species simultaneously infest bambara grains, they tend to exhibit interspecific competition where *C. maculatus dominates* over C. *subinnotatus* (Lale & Vidal, 2001; Maina & Lale, 2004). It is reported that *C. maculatus* is the most destructive species due to its shorter life cycle and high reproductive potential and it often infests a wide range of legume grains while *C. subinnotatus* infest only bambara grains (Ajayi & Lale, 2000; Lale & Vidal, 2001). During co-infestation, *C. maculatus* can cause the extinction of *C. subinnotatus* in multiple generations (Lale & Vidal, 2001). Bruchids affect bambara groundnuts from the field to the storage. Being field to storage pests, bruchids infestation commences in the field during the pod's stage whereby the females lay their eggs on developing seeds or pods or during the harvesting when the pods are left in the field to dry (Ajayi & Lale, 2000; Nyamador *et al*., 2016). Bruchids on stored bambara groundnuts grains, reduce the quality and quantity of grains and reduce the seeds germination potential and market value of the grains. The grain loss of up 99% has been reported when grains of susceptible variety is left unprotected with insecticide (Umar & Turaki, 2014). The storage infestation influenced by the level of primary infestation from the field thus the proper strategy of protection of bambara groundnuts from bruchids infestation starts by prevention of field infestation and post-harvest infestation during storage (Lale & Vidal, 2001). Various strategies are applied to control bruchids such as cultural control measures, breeding for resistance, synthetic insecticides and pesticidal plants (Ajayi & Lale, 2000). The pesticidal plants powder has been reported to be effective for control of storage insects and does not cause an undesirable impact on the health of consumers, applicators and nor-target organisms (Chikukura *et al.*, 2011; Chougourou *et al.*, 2016). However, there is limited information on the use of pesticidal plants for control of storage insects on bambara groundnuts. Thus, more research is needed to determine the efficacy of pesticidal plants in the control of bruchids in bambara groundnuts.

2.2 Prospects of pesticidal plants in bambara groundnut arthropod pest control in the field and storage

Pesticidal plants contain a mixture of bioactive compounds that act as feeding deterrents, repellents on insects or they tend to interfere with insect development (Belmain *et al.*, 2013). Plants with pesticidal effect have been used by farmers for decades for pest control in crops or livestock (Table 1) before and after the introduction of synthetic pesticides (Anjarwalla *et al*., 2016). Unlike synthetic pesticides, pesticidal plants are relatively less expensive and are ecofriendly to the environment, non-target organisms and humans (Anjarwalla *et al.*, 2016; Mkenda *et al.*, 2015a). This review has focused on the chemical compounds, potential in controlling arthropod pests in the field and storage of seven selected candidate pesticidal plants including *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia* and *C. dichogamus*.

Table 1: Common pesticidal plants found in Africa

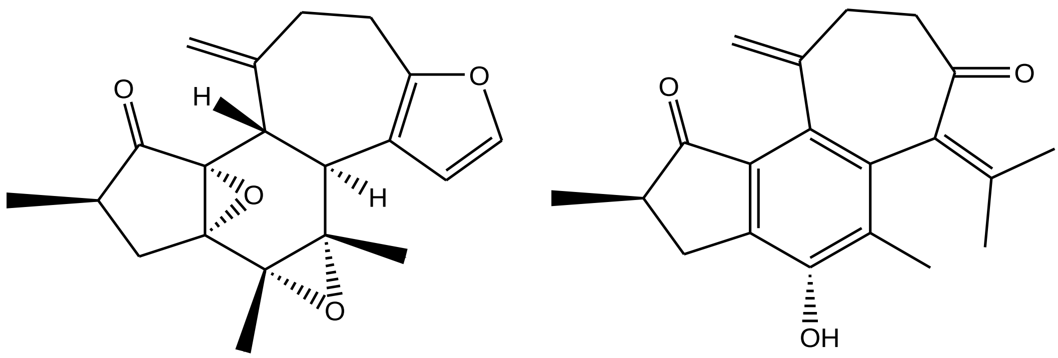
Pesticidal plant	Crop/pest (s) controlled	Reference
Pyrethrum, *Chrysanthemum cinerariifolium*	Groundnut arthropods pests: *Helotrichia serrate, Peridontopyge* spp., *Macrotermes bellicosus*	Ojiako *et al.* (2015)
Neem, Azadirachta indica	The Bean Weevil: *Acanthoscelides obtectus*	Rugumamu (2014)
Black jack, Bidens pilosa	Common beans insect pests: *Ootheca mutabilis* and *O. bennigseni, Epicauta albovittata* and *E. limbatipennis, Clavigralla tomentosicollis*, and *C. hystricodes*	Mkindi *et al.* (2017)
Mexican marigold, *Tagetes minuta*	Cabbage: *Brevicoryne brassicae*	Phoofolo *et al.* (2013)
Tickberry *Lantana camara*	Maize weevil: *Sitophilus zeamais*	Ogendo *et al.* (2003a)
Tobacco, *Nicotiana tabacum*	The Bean Weevil: *A. obtectus*	Rugumamu (2014)
Fish poison, *Tephrosia vogelii*	Common beans insect pests: *O. mutabilis* and *O. bennigseni, Epicauta albovittata* and *E. limbatipennis, C. tomentosicollis,* and *C. hystricodes*	Mkindi *et al.* (2017)
Bitter leaf, *Vernonia amygdalina*	Cowpea beetle: *C. maculatus*	Green *et al*. (2017)
Lippia javanica	Common beans insect pests: *O. mutabilis* and *O. bennigseni, E. albovittata* and *E. limbatipennis, C. tomentosicollis* and *C. hystricodes*	Mkindi *et al.* (2017)
Mexican sunflower, *Tithonia diversifolia*	Cowpea beetle: *C. maculatus*	Green *et al.* (2017)
Eucalpytus sp.	Cereals: *S. oryzae*	Campolo *et al.* (2018)
Garlic, *Allium sativum*	Maize: *S. zeamais*	Chaubey (2017)
Derris elliptica	Cabbage: *B. brassicae*	(Moyo *et al.* (2006)
Papaya, *Carica papaya*	Mustard *Lipaphis erysimi*	Baroacha *et al.* (2014)
Croton dichogamus	Storage insect pests	Qwarse *et al.* (2018)

2.2.1 The chemical and insecticidal potential of *Croton dichogamus*

Croton dichogamus Pax is a naturally growing shrub belonging to the family Euphorbiaceae extensively distributed in tropics and subtropics such as Kenya, Uganda, Ethiopia, Mozambique, Madagascar and Tanzania (Aldhaher *et al.*, 2017; Xu *et al.*, 2018; Plate 1). In Africa, America and Asia croton species are used as traditional medicines for the treatment of various ailments such as fever, diabetes, dysentery, wounds, ulcers malaria, intestinal worms, inflammation, hypercholesterolemia, digestive problems, constipation, cancer weight loss and pains (Salatino *et al.*, 2007). In Kenya and Tanzania, *C. dichogamus* is used as a dietary milk and soup supplement. The smoke from the Croton is inhaled during the treatment of respiratory infections. In addition, the plant has also been reported to be used to treat chest pains, malaria, arthritis, gonorrhea and stomachache in Kenya (Aldhaher *et al.*, 2017).

Plate 1: **The picture of *C. dichogamus*, a pesticidal plant**

The photochemistry of the plant is generally diverse possessing the compounds such as crotodichogamoin A and B (Fig. 1), crotofolanes, halimes, crothalimene A and B, crotohaumanoxide, aleuritolic, depressin, casbane and sesquiterpenoid are isolated from the roots of *C. dichogamus* (Aldhaher *et al.*, 2017; Xu *et al.*, 2018). Most of the croton species are rich in terpenoids (Salatino *et al.*, 2007), a compound with insecticidal properties (Castilhos *et al.*, 2018; Dambolena *et al.*, 2016). Silva *et al*. (2018) studied the effectiveness of the ethanolic extracts from the leaves and stems of *Croton rhamnifolius, C. jacobinensis, C. sellowii* and *C. micans* against the diamondback moth (*Plutella xylostella* L) on kales. It was found that the *C. rhamnifolius* leaf had more lethal effect (LC=14.95 mL-1) than the stem (LC=42.40 mL^{1}) and *C. sellowii* stem was found to have the lowest lethal effect (LC=1252 µg mL-1). In Tanzania, the plant is used by agro-pastoral societies in Mbulu District as a pesticide for controlling storage insect pests, medication of teeth infections and urinary tract infection (Qwarse *et al.*, 2018). Despite *C. dichogamus* being used traditionally by agro-pastoral societies in Mbulu district in Tanzania, proper application rates have not been established for optimized application. Therefore, future research is needed to establish its dosages for proper insect pest control.



Crotodichogamoin A

Crotodichogamoin B

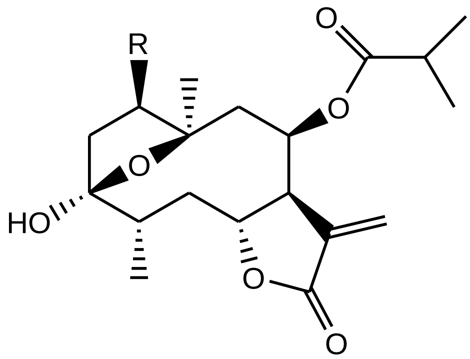
Figure 1: Chemical structure of crotodichogamoin A and B from *C. dichogamus* roots (Aldhaher *et al.*, 2017)

2.2.2 The chemical and insecticidal potential of *Tithonia diversifolia*

Tithonia diversifolia commonly known as Mexican sunflower is a prolific flowering shrub belonging to the family Asteraceae originated from central and north America (Ajao & Moteetee, 2017). Currently, *T. diversifolia* (Plate 2) is widely distributed along with the farms, roads, rivers and hills of humid and sub-humid tropics of Africa, Central America and South America (Jama *et al.*, 2000; Tagne *et al.*, 2018). In many parts of Africa, the extracts from the *T. diversifolia* plant is traditionally used as medicine for the cure of many ailments including wounds, skin diseases, stomachache, malaria, diabetes, sore throat, fever and liver pains (Moronkola *et al.*, 2007; Tagne *et al.*, 2018) and insect pests control (Mkindi *et al.*, 2017). The medicinal and insecticidal properties of the *T. diversifolia* are attributed by the presence of phytochemical constituents including sesquiterpene lactones tagitinin A, tagitinin B, tagitinin C, tagitinin D and tagitinin H (Fig. 2) (Ajao & Moteetee, 2017; Green *et al.*, 2017). Several authors including (Green *et al.*, 2017) reported the insecticidal potential of *T. diversifolia* against cowpea bruchids *C. maculatus*. It was found that the toxicity of crude extracts of *T. diversifolia* against bruchids was concentration-dependent. Yet, the crude extracts showed no significant effect on the oviposition despite the variation in concentration. Other studies by Mkenda *et al.* (2015a) and Mkindi *et al.* (2017) found that the leaf extracts of the *T. diversifolia* was effective against the insect pest of common beans such as bean foliage beetle (*O. mutabilis* and *O. bennigseni*), aphids (*Aphis fabae*) and flower beetle (*Epicauta albovittata* and *E. limbatipennis*). The application of *T. diversifolia* as pesticide reduces the cost incurred on expensive synthetic pesticides resulting in the high marginal rate of returns from farming. For example, the use of *T. diversifolia* is reported to provide the marginal rate of return of 5.32 USD/ha higher than 4.06 USD/ha obtained when synthetic pesticide is used (Mkenda *et al.*, 2015a). Additionally, the leaves of the *T. diversifolia* contain mineral nutrients about 3.5%N, 0.37%P and 4.1%K on dry matter basis so when used as green manure replenishes soil nutrients enhancing the growth and yield of the crops (Jama *et al.*, 2000). Moreover, foliar spraying of the extract from these *T. diversifolia* as a pesticide it also provide additional nutrients to the crop in the form of foliar fertilizer (Cenny *et al.*, 2013), thus, resulting to high yield of the crop. Furthermore, plants are also used as animal fodder (Osuga *et al.*, 2012).

Plate 2: The picture of *T. diversifolia,* a pesticidal plant

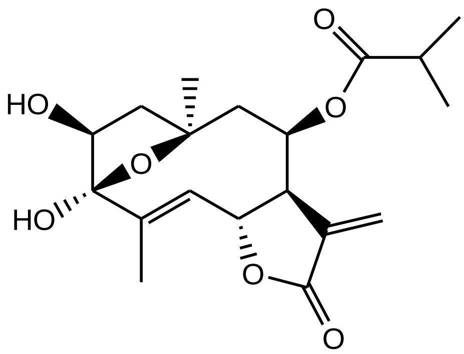
Therefore, presence of the bioactive compounds in these plants and proven pesticidal potential against arthropod pests of legumes (Green *et al.*, 2017; Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017) gives the insight to investigate its effectiveness in control of pre-harvest and post-harvest insect pest of bambara groundnuts.



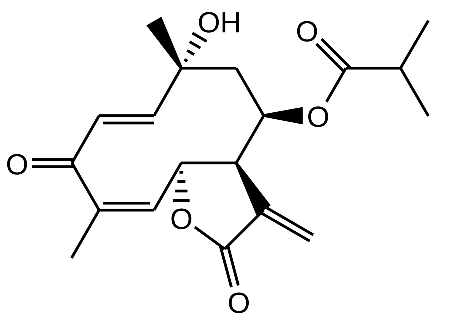
1   R = OH

1a   R = OAc

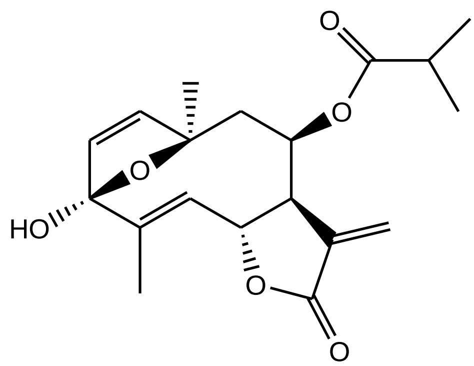
Tagitinins A



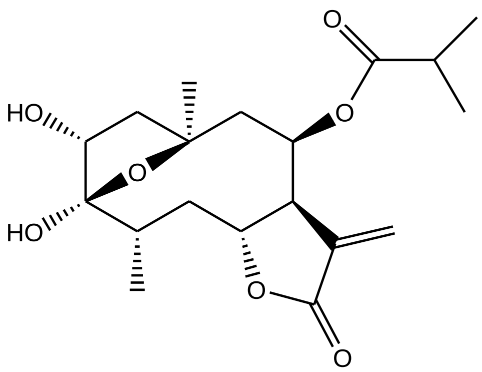
Tagitinins B



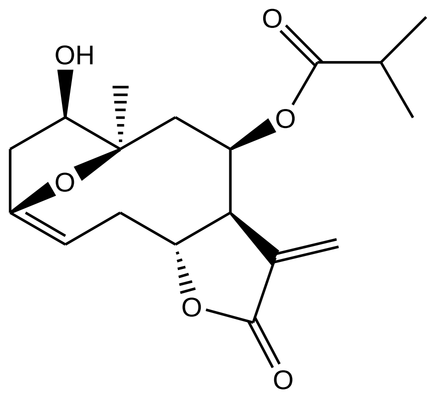
Tagitinins C



Tagitinins F



2 alpha -hydroxytirotundin, tagitinins A isomer



Dehydrated tagitinins A

Figure 2: Chemical structure of sesquiterpene lactones tagitinin A, tagitinin B, taginin C taginin F and taginin 2 alpha-hdroxytirotundin, taginins A isomer and dehydrated taginins A (Green *et al.*, 2017; Miranda *et al.*, 2015; Zhao *et al.*, 2012)

2.2.3 The chemical and insecticidal potential of *Lantana camara*

Lantana camara (Plate 3) is an ornamental plant in the family Verbenaceae originated from America. It is widely spread in tropical and subtropical regions including Eastern Africa (Shackleton *et al.*, 2017). In many parts of the world, *L. camara* is considered an invasive weed (Goncalves *et al.*, 2014; Shackleton *et al.*, 2017; Zoubiri & Baaliouamer, 2012).

Plate 3: The picture of *L. camara*, a pesticidal plant

In some countries, *L. camara* is used in preparation of the folk medicine for cure of ailments diseases such as ulcers, rheumatism, tetanus, malaria, cancer, ulcers, cancer, eczema, high blood pressure, sores and measles among others (Hernández *et al.*, 2003; Kalita *et al.*, 2012; Kurade *et al.*, 2010; Magassouba *et al.*, 2007). *Lantana camara* is regarded as poisonous to livestock such as cattle, goats, sheep, dogs and horses (Mpumi *et al.*, 2016). The toxicity of *L. camara* to animals is caused by the presence of pentacyclic triterpenoids (Fig. 3) which damage liver and generalized weakness, diarrhea, vomiting and notorious to cause photosensitivity (Durbesula *et al.*, 2015). In humans, the toxicity of *L. camara* is undetermined but several studies have suggested that ingesting green unripe fruits are toxic (Durbesula *et al.*, 2015; Sharma *et al.*, 2007). However, other studies have reported that ingestion of ripe fruits of *L. camara* poses no risk to humans (Durbesula *et al.*, 2015; Sharma *et al.*, 2007). *Lantana camara* has been reported to have insecticidal properties against several insect pests of stored grains. For example, the study conducted in Kenya by (Ogendo *et al.*, 2003a) revealed the insecticidal potential of leaf powder from *L. camara* against maize weevil (*S. zeamais*). The findings from their study showed that after 21 days *L. camara* at the rate of 7.5-10 % (w/v) resulted in 82.7% insect mortality. Moreover, another study by Rajashekar *et al.* (2014) reported the potential of *L. camara* in control of *S. oryzae* (L.) *C. chinensis* (Fab.) and *Tribolium castaneum* (Herbst.). Despite the potential of *L. camara* reported in other crops pests, there is a need to conduct more studies to understand the potential of *L. camara* against different insect pests on bambara groundnuts both in the field and on storage.

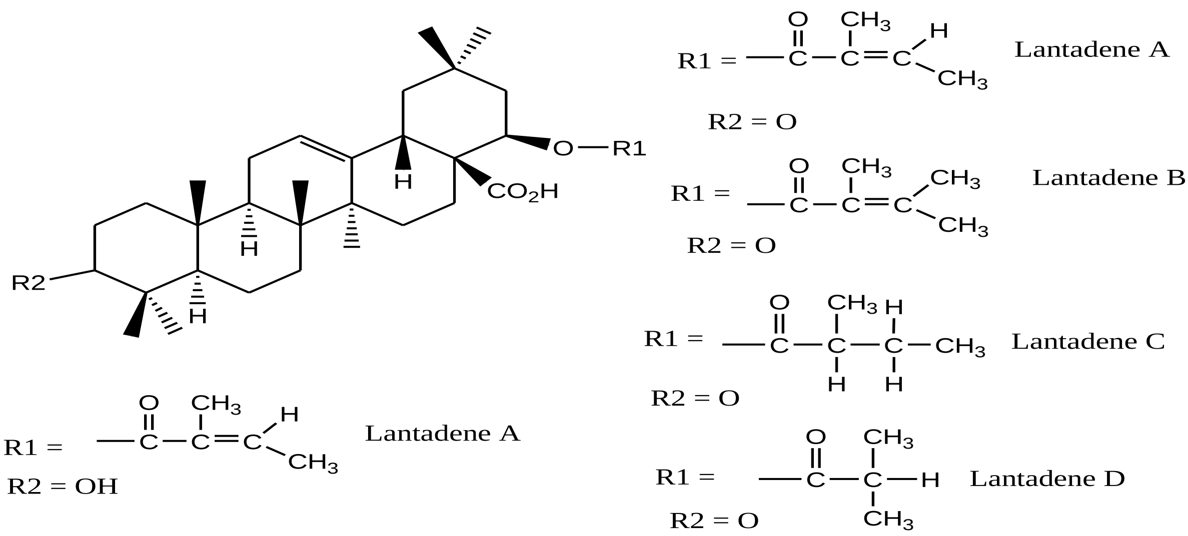


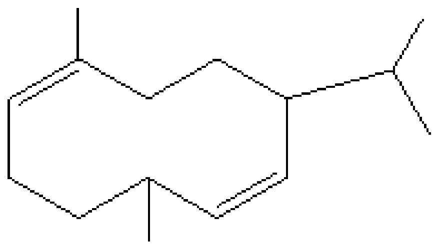
Figure 3: Chemical structures of Lantadene (Pentacyclic triterpenoids) (Mpumi *et al.*, 2016; Sharma *et al.*, 2007)

2.2.4 The chemical and insecticidal potential of *Bidens pilosa*

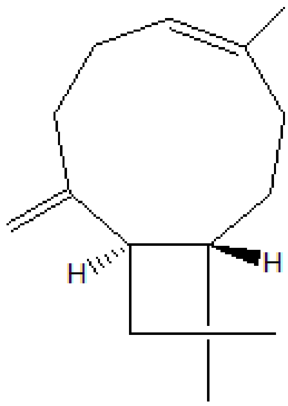
Bidens pilosa L. is an annual herb originated from South America and widely distributed around the tropical and subtropical regions (Bartolome *et al.*, 2013; Lima Silva *et al.*, 2011). *Bidens pilosa* is regarded as a noxious weed in the agricultural fields (Arthur *et al.*, 2012; Plate 4). In sub-Saharan countries, the young tender leaves of *B. pilosa* are consumed as a vegetable in times of food scarcity (Arthur *et al.*, 2012). In many parts of the world including Africa, Asia and tropical America; *B. pilosa* is used as medicinal plant in treatment of inflammation, bacterial infection, antioxidant, liver protection, regulating blood pressure and blood sugar (Arthur *et al.*, 2012; Ashafa & Afolayan, 2009; Deba *et al.*, 2008; Geissberger & Séquin, 1991). The medicinal role offered by this plant is a result of the presence of bioactive compounds. For instance, the antimicrobial and antimalarial function of *B. pilosa* is due to the presence of polyacetylenes in the plant (Geissberger & Séquin, 1991).

Plate 4: The picture of *B. pilosa*, a pesticidal plant

Major bioactive compounds identified from leaves and flowers of the *B. pilosa* includes sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene (Deba *et al.*, 2008; Lima Silva *et al.*, 2011) (Fig. 4**)**. *Bidens pilosa* is also reported to have anti-insect function. For example, a study conducted by Goudoum *et al.* (2016) revealed the insecticidal potential of essential oils from the leaves of *B. pilosa* against *C. maculatus*. Renuka *et al.* (2014) investigated the toxicity of methanol and acetone extracts of *B. pilosa* against stored pests of kidney beans, the *A. obtectus* (Say) and *Zabrotes subfasciatus* (Boheman) (Coleoptera: Chrysomelidae). Both acetone and methanol extracts from the *B. pilosa* plant were found to cause 100% mortality of *A. obtectus* and *Z. subfasciatus.* Moreover, other studies conducted by Mkindi *et al.* (2017) and Tembo *et al.* (2018) revealed the insecticidal potential of *B. pilosa* against insect pests of common beans such as foliage beetles (*O. mutabilis* and *O. bennigseni*), flower beetle borers (*Epicauta albovittata* Gestro and *E. limbatipennis* Pic), aphids (*A. fabae*) and pod suckers (*Clavigralla spp*.). In spite of the fact that the insecticidal function of the plant has been reported by many authors (Goudoum *et al.*, 2016; Mkindi *et al.*, 2017; Tembo *et al.*, 2018) however, it has not been sufficiently tested on bambara groundnut pests. Thus, future research needs to be conducted to determine efficacy *B. pilosa* on insect pests on bambara groundnuts.



Germacrene-D



β-caryophyllene

Figure 4: Sesquiterpenes germacrene-D (Yang *et al.*, 2005) and (b) β-caryophyllene (Gertsch *et al.*, 2008) from *B. pilosa*

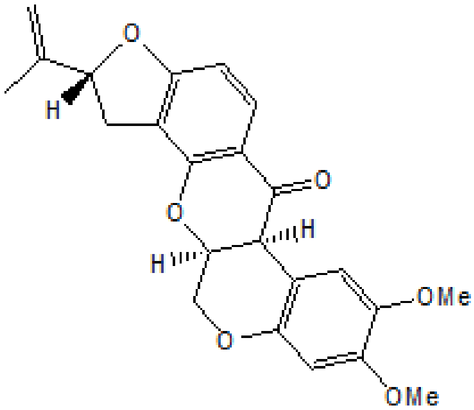
2.2.5 The chemical and insecticidal potential of *Tephrosia vogelii*

Tephrosia vogelii Hook. f. (Plate 5) is the herb belonging to the Family Leguminosae native to tropical Africa that is highly distributed in tropical America and South and Southeast Asia mainly used as fish poison (Dzenda *et al.*, 2009). *Tephrosia vogelii* is also used as a pesticide to control pests on animals and on crops on the field and storage and also enrich soil nutrients (Stevenson *et al.*, 2012). The phytochemical screening of *T. vogelii* showed that the plant possesses diverse bioactive chemical compounds including three chemotypes (Fig. 5). The chemotype 1 (C1) which contains rotenoids required for pest control and chemotype 2 (C2) which do not contain rotenoids (Belmain *et al.*, 2012; Stevenson *et al.*, 2012). However, it is reported that rotenoids (deguelin, tephrosin, α-toxicarol and sarcolobine) differ in their effectiveness against insect pests. Rotenone is the most active rotenoid than deguelin, tephrosin while obovatin 5-methyl ether found in chemotype 2 is not active (Belmain *et al.*, 2012). The Chemotype 3 (C3) is a hybrid of the chemical profiles of the Chemotype 1 and chemotype 2 (Mkindi *et al.*, 2019).

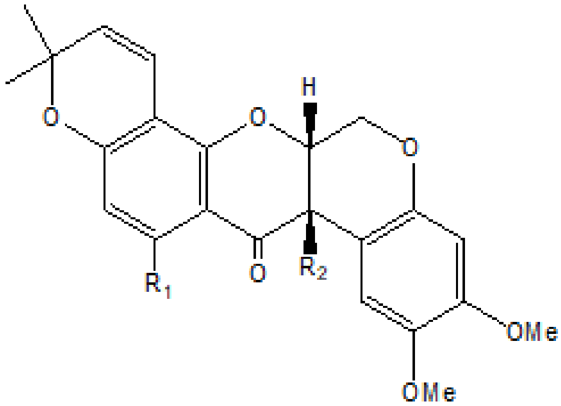
Several studies have reported the insecticidal potential of the active chemical compounds of *T. vogelii*. For example, a study conducted by Ogendo *et al.* (2003a) revealed that *T. vogelii* leaf powder killed maize 85.0 – 93.7% of weevil (*S. Zeamais*) in stored maize grain. It was found that the mortality of maize weevil caused by *T. vogelii* leaf powder was proportional to the exposure time and concentration. Closely related findings were reported by Koona and Dorn (2005) when they investigated the potential of extracts from *T. vogelii* for the control of bruchids on stored legumes. Their study showed that the extracts from *T. vogelii* had insecticidal potential against bruchid species (*A. obtectus, C. maculatus* and *C. chinensis*) on stored legumes.

Plate 5: The picture of *T. vogelii* a pesticidal plant

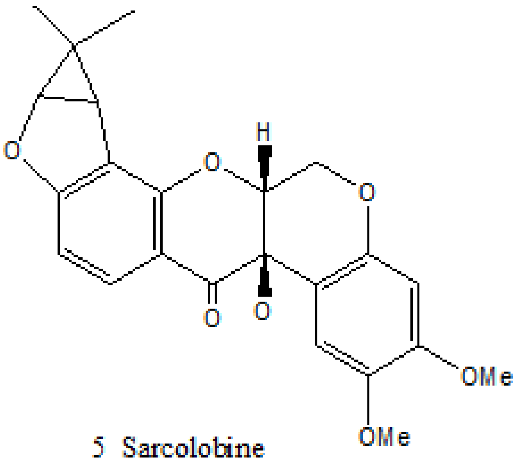
Moreover, the use of *T. vogelii* in controlling common bean pests has been reported to provide high marginal rate of return 5.62 (USD/ha) as compared with synthetic pesticide lambda-cyhalothrin pyrethroid (Karate) 4.06 USD/ha (Mkenda *et al.*, 2015a). The low marginal rate of return (USD/ha) for synthetic pesticides is due to its high market price and ultimately high marginal cost than when *T. vogelii* was used. Despite the insecticidal and economic benefits offered when *T. vogelii* is used to control pests on crops such as common beans, however, there is limited information on its potential in insect control on bambara groundnuts. Therefore, future research should be conducted to determine potential of *T. vogelii* for bambara groundnuts insect control on the field and on storage.



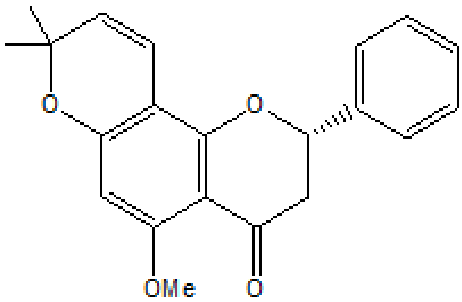
1 Rotenone



2 R1 = H, R2 = OH; Tephrosin
3 R1 = R2 = H; Deguelin
4 R1 = OH, R2 = H; Alpha - Toxicarol



5 Sarcolobine



6 Obovatin-5-*O*-methylether

Figure 5: 1-5; *T. vogelii* Chemotype compounds and 6; *T. vogelii* Chemotype 2 (Belmain *et al*., 2012; Stevenson *et al*., 2012)

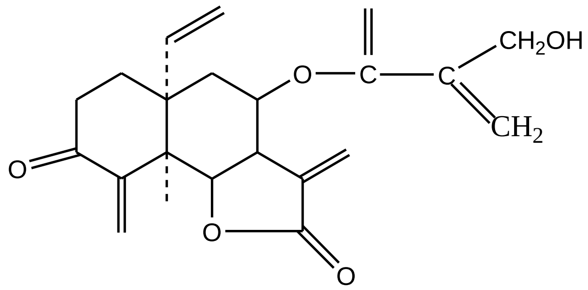
2.2.6 The chemical and insecticidal potential of *Vernonia amygdalina*

Vernonia amygdalina Del, (Plate 6) is a small perennial shrub belonging to the family Asteraceae that is widely distributed in tropical Africa. *Vernonia amygdalina* is commonly known as bitter leaf because its bitter taste (Ijeh & Ejike, 2011). The bitter taste is attributed to the presence of anti-nutritional factors in *V. amygdalina* such as alkaloids, saponins, glycosides and tannins (Bonsi *et al.*, 1995; Clement *et al.*, 2014). *Vernonia amygdalina* have many traditional uses in African countries. In Nigeria, the leaves of bitter leaf are used as a vegetable or as a spice in a soup whereby the bitterness of the leaves is reduced to the desired level by macerating in hot water (Clement *et al.*, 2014; Farombi & Owoeye, 2011). In Ethiopia, the leaves of *V. amygdalina* are used as hops in preparing tela beer (Farombi & Owoeye, 2011). The *V. amygdalina* leaves are consumed due to their antioxidant benefits

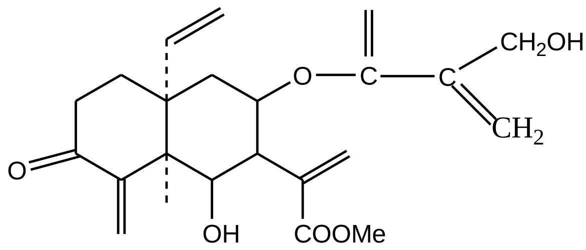
(Alara *et al.*, 2017; Igile *et al.*, 1994). In most African countries *V. amygdalina* is used as a folk medicine as remedies against ailments such as emesis, loss of appetite, diabetes, nausea, dysentery and other gastrointestinal tract problems, sexually transmitted diseases, diabetes mellitus (Farombi & Owoeye, 2011) and antimalarial (Masaba, 2000).

Plate 6: The picture of *V. amygdalina*, a pesticidal plant

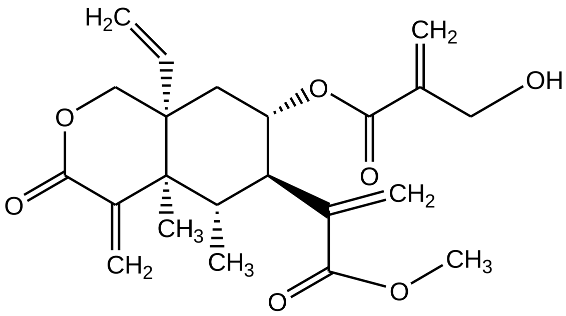
The phytochemical investigation of the leaves of *V. amygdalina* revealed presence of number of bioactive compounds such as sesquiterpene lactones including the vernolide and vernodalol (Fig. 6) (Erasto *et al.*, 2006; Igile *et al.*, 1994), flavonoids such as luteolin, luteolin 7-O-glucuronide, luteolin 7-O-glucosides, steroid glycosides, and vernonioside A, B, A1, A2, A3, B2, B3 and A4 (Farombi & Owoeye, 2011; Igile *et al.*, 1994). The sesquiterpene lactones found in *V. amygdalina* have insect antifeedant, antitumoral, antifungal, and cytotoxic properties (Erasto *et al.*, 2006). Several studies have reported the insecticidal potential of leaf powders of *V. amygdalina* against *C. maculatus* (F.) (Akunne *et al.*, 2014), beans weevil (*A. obtectus*) (Adeniyi *et al.*, 2010) and maize weevil (*S. zeamais*) (Asawalam & Hassanali, 2006) and field insects of common beans (*Aphis fabae*), bean foliage beetle (*O. mutabilis*) and *O. bennigseni*), flower beetle (*Epicauta albovittata* and *E. limbatipennis*) and pod suckers (*Clavigralla tomentosicollis, C. schadabi* and *C. hystricodes*) in a study conducted in Tanzania and Malawi (Mkindi *et al.*, 2017). However, despite its potential in controlling insects in other crops such as common beans, future research is needed to test the efficacy of *V. amygdalina* extracts in controlling field and storage insect pests of bambara groundnuts.



Vernodalin



Vernodalol



Epivernodalol

Figure 6: Structure of compounds isolated from *V. amygdalina* (Farombi & Owoeye, 2011; Green *et al.*, 2017)

2.2.7 The chemical and insecticidal potential of *Lippia javanica*

Lippia javanica (Burm F.) Spreng (Plate 7) is an erect woody perennial herb belonging to the family Verbenaceae. *Lippia javanica* is naturally growing in the bushes, along the roadsides, hillsides and farms in eastern, central and southern Africa and in the Indian subcontinent (Maroyi, 2017; Mwanauta *et al.*, 2014; Pascual *et al.*, 2001). In many African countries and Indian subcontinent, *L. javanica* are traditionally used as herbal tea due to its ethno-medicinal properties for cure of ailments like malaria, fever, colds, cough, healing wounds, diarrhea, chest pains, bronchitis, asthma, skin diseases and repelling mosquitos (Endris *et al.*, 2016). In Kenya, the leaves and twigs of *L. javanica* are used as food additives whereas in India, leaves are used as a leafy vegetable. In Botswana, South Africa and Zimbabwe; the leaves, stems, and twigs are used in preparations of the herbal tea (Maroyi, 2017).

Plate 7: The picture of *L. javanica,* a pesticidal plant

The phytochemical analysis of *L. javanica* revealed the presence of camphor as the major component with minor components such as camphene, α-pinene, eucalyptol, Z and E α-terpineol, cymene, linalool, caryophyllene, thymol, α-cubebene and 2-carene (Mkenda *et al.*, 2015a). The camphor (Fig. 7) a monoterpenoid commonly found in *Cinnamonum camphora* is reported to have insecticidal potential (Chen *et al.*, 2018; Gillij *et al.*, 2008; Mkenda *et al.*, 2015a; Singh *et al.*, 2014; Tembo *et al.*, 2018). The insecticidal function of *L. javanica* has been reported by several authors. For example, studies by Mkenda *et al.* (2015a), Mkindi *et al.* (2017) and Tembo *et al.* (2018) reported the insecticidal property of *L. javanica* against field insects of common beans such as bean foliage beetle (*O. mutabilis* and O. *bennigsen*i), aphids (*Aphis fabae*) and flower beetle (*Epicauta albovittata* and *E. limbatipennis*). Another study conducted in Zimbabwe revealed that the aqueous leaf extracts of *L. javanica* have acaricidal activity against cattle ticks and acute oral toxicity in mice (Madzimure *et al.*, 2011). Their study found that the acaricidal effect was dependent on the dose of the extract and exposure time. A study by Wafula *et al.* (2019) as well revealed the effectiveness of aqueous extracts of *L. javanica* leaves against the cowpea aphids. Their study established that 10% (w/v) extracts from the dried leaves powder significantly reduced the aphids infestation on cowpeas. Furthermore, the leaf powders demonstrated insecticidal potential against storage insect pests of maize and cowpeas including *S. zeamais*, *C. maculatus, Prostephanus truncates*, *Tribolium spp* and *Sitotroga cerealella* (Chikukura *et al.*, 2011). Despite the fact that *L. javanica* contains bioactive compounds proved with insecticidal potential, however, it has not been evaluated against insect pests of bambara groundnuts. Therefore, future research is needed to investigate its potential against the pre-harvest and post-harvest insect pests of bambara groundnuts.

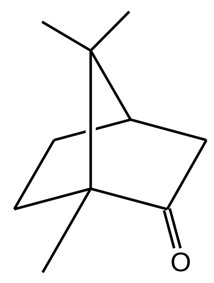


Figure 7: Chemical structure of camphor (Yim *et al.,* 2014)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study location

The study to assess the effectiveness of selected pesticidal plants against field and storage pests of bambara groundnuts was set at Nelson Mandela Institution of Science and Technology (NM-AIST), Arusha, Tanzania.

3.2 Pesticidal plant extracts preparation

The fresh leaves of *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* were collected from natural habitat in Arusha and Moshi region in Tanzania. These sites were selected based on the available grey information indicating the availability of these plants. Crude extracts from these plants were prepared as described by Anjarwalla *et al.* (2016) and Mkenda *et al.* (2015a). In brief, the pesticidal plants leaves from each plant were air-dried under the shade separately. Then the leaves were separately crushed using an electric grinding mill to make the powder, which was stored in plastic buckets in dark condition to avoid degradation of bioactive compounds until when required for subsequent applications. Plant extracts were prepared from dry leaves powder using clean tap water in the concentration of 10% (w/v) and 0.1% soap was added during the extraction of the active compounds from the pesticidal plant materials in water. The mixture was left for 24 hours and filtered twice using the clean cloth to remove large particles of plant materials prior to spraying.

3.3 Experimental design and treatments for the field experiment

The field was prepared by clearing the bush and the land was ploughed and disc harrowed prior to planting of the bambara groundnut seeds. The bambara groundnuts seeds (Tanbam) used in this experiment were obtained from the Tanzania Agricultural Research Institute (TARI-Naliendele). Two seeds were planted per hole in 60 cm by 10 cm inter-row and intra-row respectively in 5 x 5 m plot. The seeds were planted on 12th April 2019. After emergence plants were thinned leaving one plant per hole. A randomized complete block design (RCBD) was used to set the field experiment with 8 treatments replicated 4 times. Treatments consisted of six (6) pesticidal plants leaf extracts namely *B. pilosa, L. camara, T. vogelii, V.*

amygdalina, L. javanica and *T. diversifolia*, synthetic insecticide (lambda-cyhalothrin) as the positive control and untreated plot as the negative control. The distance between replication was 2 m and the distance between plots was 1 m (Appendix 1). The pesticidal plant extracts were sprayed 2 weeks after the emergence of the bambara groundnuts throughout the growing season at the interval of 7 days. Positive control karate (lambda-cyhalothrin 5% EC), Syngenta, was applied by following the manufacturer's recommendation. The pesticidal plants extracts were sprayed above and under the leaves using 15 L Knapsack sprayers during the evening to avoid direct sunlight which might cause decomposition of bioactive compounds to maximize contact with insects as described by Anjarwalla *et al*. (2016) and Mkenda *et al*. (2015a). The earthing up was done at 90 days after planting.

3.4 Data collection

3.4.1 Evaluation of the effectiveness of crude extracts of selected pesticidal plants on the management of bambara groundnuts pests under field conditions and their effects on beneficial arthropods

The arthropod pests and beneficial arthropods were observed by randomly selecting five (5) inner plants in each plot. The pests and beneficial arthropods were identified and their numbers counted before application of the treatments. The abundance/numbers of small arthropods such as aphids and red spider mites were scored using the categorical index of 1-5; where, 0 = none; 1 = few and scattered individuals; few isolated colonies; 3 = several isolated colonies; 4 = large isolated colonies; and 5 = large continuous colonies (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017). Large arthropods such as foliage beetles, mealybugs and leafhoppers and ladybird beetle, spiders, hoverflies and wasps were counted. Unidentified pests were collected and preserved in 70% ethanol for further identification by Tropical Pesticides Research Institute (TPRI).

3.4.2 Assessment of incidences and severity of different arthropods damage on bambara groundnuts

Five (5) inner plants were randomly selected in each plot where the number of plants affected was counted and the incidence of the key pests was determined as the proportion of the affected plants sampled to the total number of plants sampled in each plot. The plant damage severity from key arthropod pests was determined by whole plant assessment of the five (5) randomly selected inner plants using a scales 0 - 4; where, 0 = 0 % damage, 1 = showing damage from 1 - 25%, 2 = showing damage from 26 - 50%, 3 = showing damage from 51 - 75%, 4 = showing damage from 76 - 100% as described by Kisetu *et al.* (2014), Mkenda *et al.* (2015a) and Mkindi *et al.* (2017). The data collection started two weeks after the emergence of the crop at the interval of seven (7) days.

3.4.3 Evaluation of the effectiveness of the application of pesticidal plant crude extracts on yield and yield components of bambara groundnut

Five (5) plants were randomly selected from every plot and number of pods plant^{-1}, the number of seeds pod^{-1} were counted and recorded. After harvesting the entire plot (except plants on the edge of each plot), the weight of 100 seeds, pod yield (kg plot^{-1}) and seeds yield (kg plot^{-1}) was weighed and recorded. The seeds yield (kg ha^{-1}) was measured after drying and threshing then the yield was converted to kg ha^{-1}. The yield and yield components was compared between the treated and the untreated plots.

3.5 Evaluation of the effectiveness of powder of selected pesticidal plants on managing bruchids on bambara groundnuts

3.5.1 Collection and preparation of plant materials

The fresh leaves of *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* leaves were collected during the dry season around roads and farms in Arusha and Moshi in Tanzania. The pesticidal plants leaves were air - dried under the shade at room temperature (22 °C – 26 °C) and relative humidity (RH) of 75 ± 5% for 14 days. The dry leaves were ground using an electric grinding mill to form the powder which were stored in 10 L plastic containers covered with the airtight - lid in dark condition to avoid degradation of bioactive compounds until when required for subsequent applications (Anjarwalla *et al.*, 2016; Mkenda *et al.*, 2015a).

3.5.2 Collection and rearing bruchids

The stock bruchids used in this study were obtained from infested bambara groundnuts collected from the Singida Municipal Market in Central Tanzania. The insects were reared on untreated bambara groundnut grains kept in plastic buckets of 10 L filled with 5 kg of untreated bambara groundnuts grains. The containers for rearing bruchids were covered with a 1mm mesh to prevent bruchids from escaping from the container. The containers were kept under room temperature (22 °C – 26 °C) and relative humidity (RH) 75 ± 5% at the Nelson Mandela Institution of Science and Technology (NM-AIST), Tanzania in a storage room.

3.5.3 The experimental setup

The bambara groundnuts grains used in this study were obtained from the Tanzania Agricultural Research Institute (TARI - Naliendele, Mtwara - Tanzania). The bambara grains were cleaned by winnowing and sorted to remove damaged grains. A 1.5 kg of clean, untreated bambara groundnut grains were weighed into cotton storage bags and admixed with powders from *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* leaves at the rate of 10% (w/w). The positive control, Actellic Dust (Pirimiphos-methyl), Syngenta was applied as per manufacturer's recommendation while the negative control remained untreated. The experiment was laid out in a randomized complete block design (RCBD) with (6) replications.

3.5.4 Data collection

A grain sample of 150 gm was drawn from each storage bag using a metal grain sampler. The grain was sieved for easy counting of the number of live bruchids, number of dead bruchids, number of damaged seeds, number of seeds with eggs attached on the surface were counted after 30 days' interval for all treatments for 180 days. After the assessment, the grains, live insects and pesticidal plant powder were returned into the respective containers. The dead bruchids were removed and discarded after every counted to avoid re-counting the same dead insect. The percent insect mortality rate (MR) was calculated as described by Ogendo *et al.* (2003) and Chougourou *et al.* (2016);

$$MR\ (\%) = \frac{No.of\ dead\ insects}{Total\ number\ of\ insects} X100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

The mortality of insects due to treatments was corrected using Abbott's correction formula (WHO, 2016).

$$Corrected\ mortality\ (\%) = \frac{(\%Observed\ mortality - \%Control\ mortality)}{(100 - \%Control\ mortality)} X\ 100 \ldots (ii)$$

3.5.5 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using the STATISTICA 8^{th} edition. The Fisher's Least Significance Difference (LSD) was used to compare treatment means at P = 0.05 level of significance. Microsoft excel software was used to generate graphs.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Abundance of arthropod pests on bambara groundnut plants

Figure 8 shows the results of the treatment of the bambara groundnut with the leaf extract of the pesticidal plants (*B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia*), synthetic insecticide (lambda-cyhalothrin 5% EC) as the positive control and untreated plot as the negative control. The results indicate that there was a significant difference between treatments ($P \leq 0.001$) in the abundance of foliage, aphids, mealybugs, red spider mites and leafhoppers, on bambara groundnuts plants. The highest numbers of foliage beetles (0.38 ± 0.051), aphids (0.92 ± 0.084), mealybugs (0.24 ± 0.041 and leafhoppers (2.51 ± 0.148) was observed in untreated plots. Contrary to expectations, red spider mites (0.60 ± 0.093) were observed only in plots treated with synthetic pesticide (Appendix 2). The treatment with the positive control (Karate), *T. vogelii* and *T. diversifolia* were the most effective treatment in the control of the infestation of foliage beetles, aphids, mealybugs and leafhoppers on bambara groundnut plants in the field. Other pesticidal plants leaf extracts were found relatively effective but not as effective as compared with positive control.

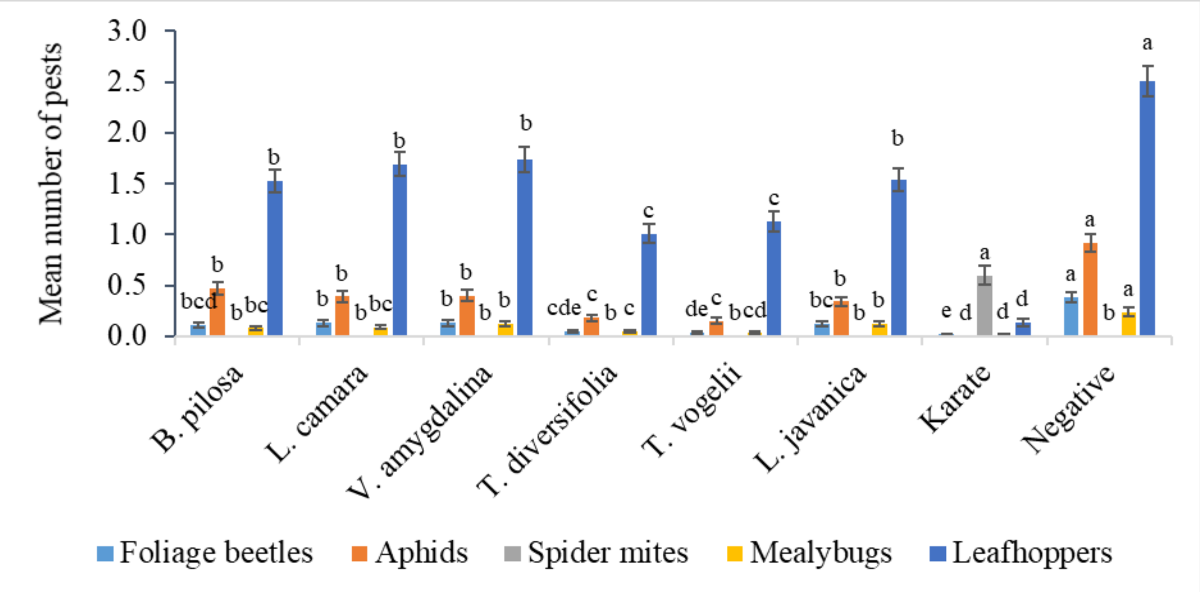


Figure 8: Abundance of key arthropod pests on bambara groundnut plants

4.1.2 Abundance of beneficial arthropods

The results of the treatments with pesticidal plants leaf extracts, synthetic pesticide and untreated plots on the abundance of beneficial arthropods ladybird beetle, hoverfly, wasps and spiders is presented in Fig. 9. The results showed that pesticidal plants had little impact on beneficial arthropods as compared with synthetic pesticide where few beneficial arthropods were observed. The statistical analyses showed that there was a significant difference ($P \leq 0.001$) between the pesticidal plants extracts, negative control and positive control. The higher number of ladybird beetles (0.33 ± 0.046) and hoverflies (0.39 ± 0.057) were observed in untreated plots whereas, the higher number of spiders (0.18 ± 0.029) were observed in plots treated with *L. camara* leaf extracts and the higher number of parasitic wasps (0.13 ± 0.03) were observed in plots treated *B. pilosa*. The least number of beneficial arthropods were observed in pots treated with synthetic pesticide (0.04 ± 0.021, 0.09 ± 0.021, 0.02 ± 0.010 and 0.05 ± 0.016 for ladybird beetle hoverfly, spiders and wasps respectively (Appendix 3).

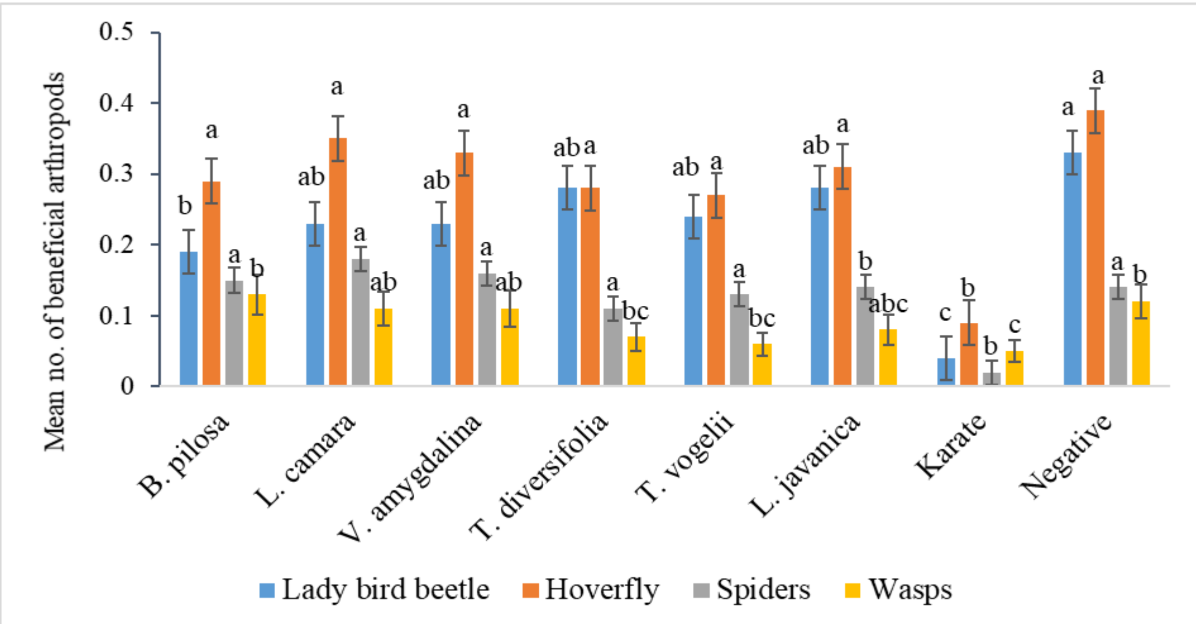


Figure 9: Abundance of beneficial arthropods

4.1.3 Incidences and damage severity of different in arthropods damage on bambara groundnuts

Plates 8, 9 and 10 shows the bambara groundnut plants damaged by foliage beetles, aphids and red spider mites respectively. Figure 10 and Fig. 11 respectively represent the pest's incidence (%) and plant damage inflicted by the arthropod pests on bambara groundnut treated with pesticidal plant extract, synthetic pesticide (karate) and untreated plots. The statistical analysis showed that the effect of the treatments was significantly different ($P \leq 0.001$) on the incidence and plant damage respectively. Among all pesticidal plants, *T. vogelii* and *T. diversifolia* were the most effective pesticidal plant in preventing the infestation and damage of the plants by the pests. Generally, the highest pest's incidence (%) and plant damage were recorded in untreated plots. The higher proportions of the plants infested with foliage beetles (20.00 ± 3.428), aphids (31.67 ± 3.722), mealybugs (11.67 ± 3.055) and leafhoppers (56.67 ± 5.667) were observed in untreated plots whereby the higher proportion of the plants infested with spider mites (11.67 ±4.179) (Appendix 4) were observed in plots treated with synthetic insecticide (karate). The higher proportion of the plants was infested by leafhoppers as compared with other pests. The plants damage followed the similar trend for foliage beetles (0.25 ± 0.032), aphids (0.61 ± 0.059), mealybugs (0.15 ± 0.025) and leafhoppers (1.07 ± 0.064) observed in untreated plots and red spider mites (0.51 ± 0.076) was observed in plots sprayed with karate (Appendix 5).

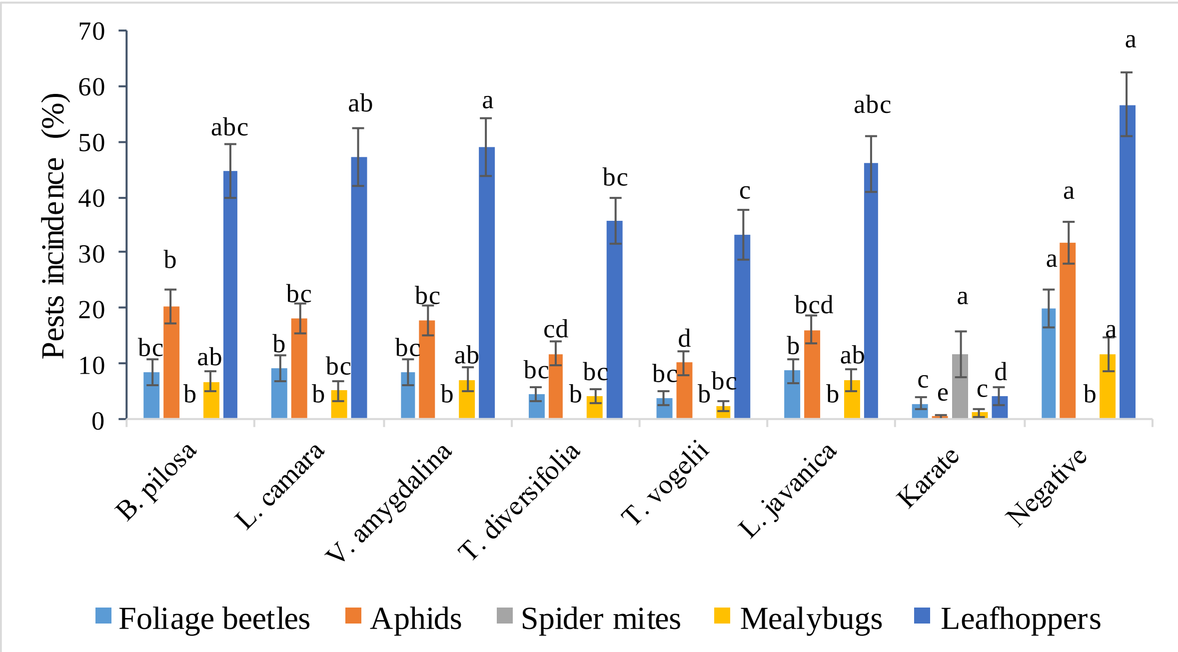


Figure 10: Percentage of bambara groundnut plants infested by key pest species

Plate 8: Bambara plant damaged by foliage beetles

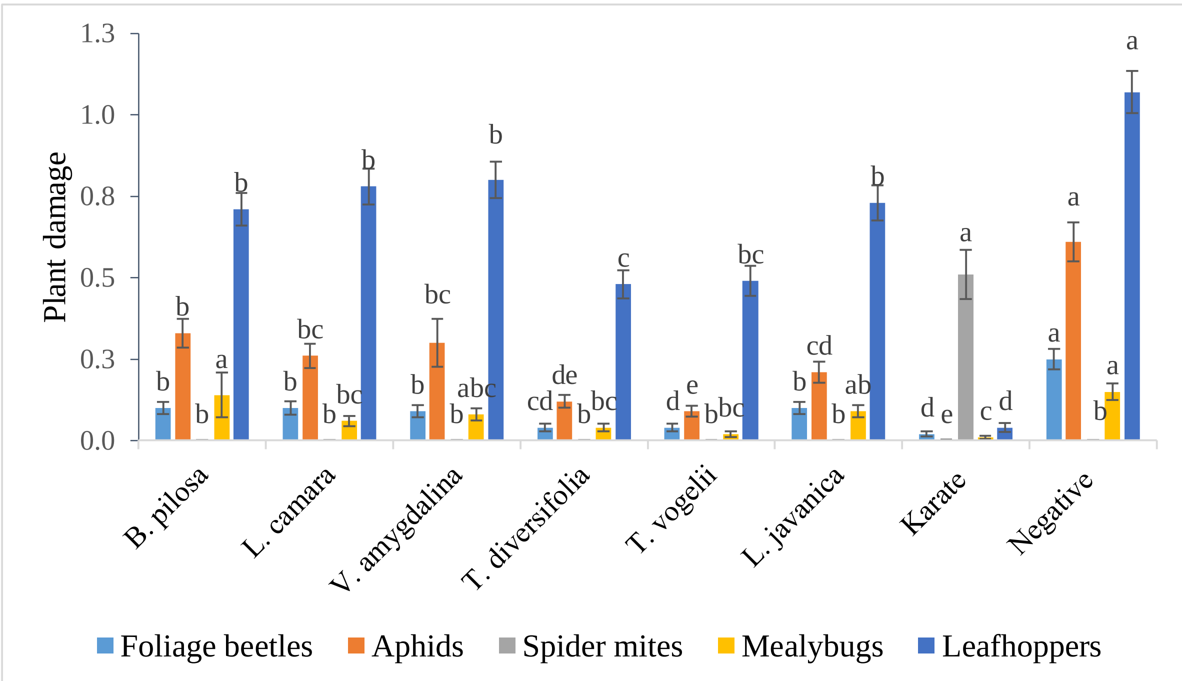


Figure 11: Bambara groundnut plants damage by key pests.

Plate 8: Bambara plant damaged by aphids

Plate 9: Bambara groundnut plant damaged by red spider mites

4.1.4 Yield and yield components of bambara groundnut

Figure 12 shows the results of the treatment of the bambara groundnut with pesticidal plants, karate (positive control) and untreated plots. The results indicate that there was a significant difference ($P \leq 0.001$) in the number of pods plant^{-1}, the number of seeds plant^{-} and the weight of seeds (100 seeds weight). There was no significant difference in pod yield (kg ha^{-1}), seeds yield (kg ha^{-1}) across the treatments. However, the highest number of pods per plant was recorded in plots treated with *L. camara* (16.25 ± 0.854) whereby the lowest number of pods per plant was observed in negative control plots. The plots treated with *L. javanica* displayed the highest number of seeds pod^{-1} (1.17 ± 0.049) whereas; the lowest number of seeds per pod was observed in plots treated with *B. pilosa* (1.05 ± 0.020). Moreover, the highest weight of seeds (100 seeds weight) was observed in plots treated with *T. diversifolia* (39.90 ± 2.327) whereas; on the other hand, the least weight of 100 seeds was observed in plots treated with *L. javanica* (28.85 ± 2.156). The highest pod yield (kg ha^{-1}) (493.25 ± 86.765) was observed in in plots treated with *T. diversifolia* whereas, highest seeds yield (kg ha^{-1}) (289.35 ± 36.938) were observed in both plots treated with *T. diversifolia* and *T. vogelii* (Appendix 6).

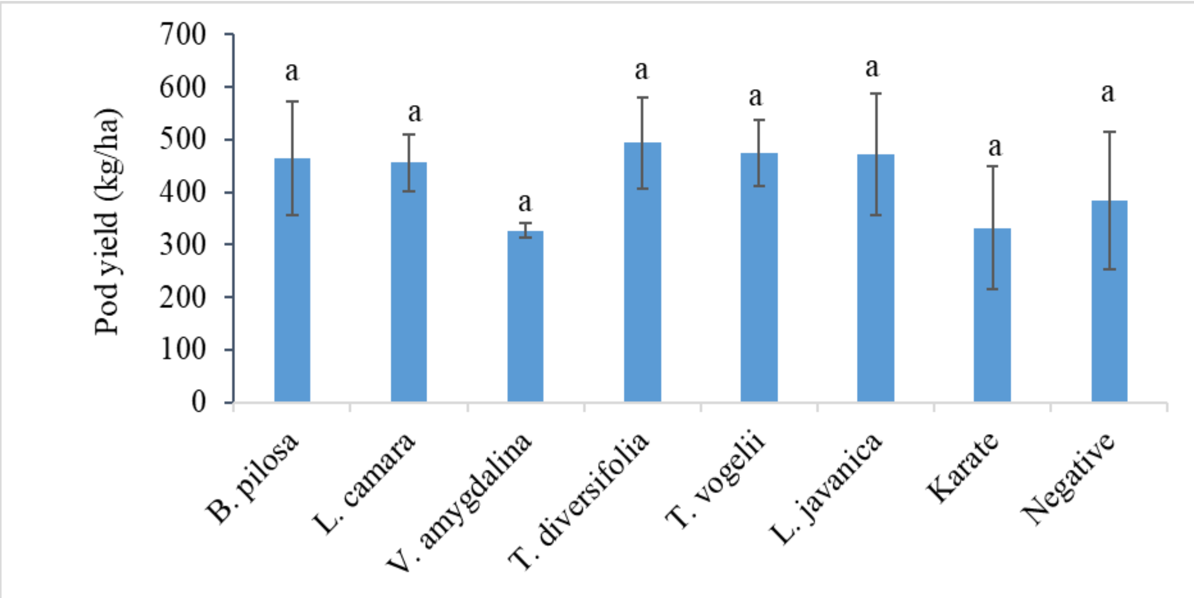


Figure 12: Bambara groundnut pod yield (kg ha^{-1})

4.1.5 Live *C. maculatus* on bambara groundnuts

The results of the effectiveness of the pesticidal plant powders are presented in Table 2. The findings from this study revealed that all pesticidal plants powder significantly reduced the number of live *C. maculatus* in the bags throughout the storage period ($P \leq 0.001$). The untreated bags (negative control) generally contained the highest number of live bruchids (5.00 ± 1.069, 10.71 ± 1.209, 27.57 ± 1.172, 61.00 ± 4.593) for 30, 60, 90 and 120 days; respectively. For 150 and 180 days, the highest numbers of live insects were observed on bags treated with *T. diversifolia* and *C. dichogamus*. *Tephrosia vogelii* dry leaf powder demonstrated very high effectiveness in preventing the infestation and emergence of bruchids in a similar way as the positive control (actellic dust). Pesticidal plants powder; *B. pilosa*, *L. camara*, *V. amygdalina*, *L. javanica* and *C. dichogamus* showed varying effectiveness against the infestation of *C. maculatus* on bambara groundnut seeds. The number of live insects generally increased from 30 - 120 days for all treatments. The trend of increase of live insects was maintained for the seeds treated with actellic dust, *T. vogelii*, *T. diversifolia* and *C. dichogamus*. However, for the bags treated with *B. pilosa*, *L. camara*, *V. amygdalina and L. javanica* the number of live bruchids progressively decreased from 150 - 180 days.

Table 2: Mean number of live insects (*C. maculatus*) in stored bambara groundnuts

Treatments	Mean ± SE of live *C. maculatus*					
	30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
B. pilosa	1.83 ± 0.601b	5.17 ± 0.872b	18.00 ± 2.463b	34.17 ± 4.331b	9.00 ± 2.921a	8.00 ± 2.309bc
L. camara	1.67± 0.558b	4.83 ± 0.703bc	18.17 ± 5.564b	34.00 ± 6.748b	11.50 ± 2.941a	10.33 ± 2.525b
V. amygdalina	1.33 ± 0.558bc	5.00 ± 1.000b	17.50 ± 4.410b	33.50 ± 4.904b	7.83 ± 0.946ab	4.00 ± 1.291c
T. diversifolia	0.50 ± 0.342bc	2.83 ± 0.401cd	6.83 ± 1.376cd	9.50 ± 1.335d	12.50 ± 1.229a	22.00 ± 3.587a
T. vogelii	0.00 ± 0.000c	0.00 ± 0.000e	0.50 ± 0.342d	1.00 ± 0.258d	1.67 ± 0.333c	3.33 ± 1.687c
L. javanica	0.83 ± 0.307bc	3.33 ± 0.333bc	12.50 ± 1.893bc	20.33 ± 3.739c	11.00 ± 3.000a	8.00 ± 2.191bc
C. dichogamus	0.33 ± 0.211bc	1.17 ± 0.477de	3.83 ± 0.749d	9.17± 0.946d	10.83 ± 1.662a	17.00 ± 1.693a
Actellic Dust	0.00 ± 0.000c	0.00 ± 0.000e	0.29 ± 0.184d	1.86 ± 0.553d	3.29 ± 0.606bc	6.00 ± 1.195bc
Negative Control	5.00 ± 1.069a	10.71 ± 1.209a	27.57 ±1.172a	61.00 ± 4.593a	9.43 ± 1.811a	4.00 ± 1.069c
One-way ANOVA						
F-statistic	**9.04*** **	**24.34*** **	**14.05*** **	**29.82*** **	**3.80** **	**9.71** **

; * significant at $P \leq 0.05$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) using Fisher's Least Significant Difference (LSD) test

4.1.6 Mortality of *C. maculatus*

Table 3 shows the mortality of *C. maculatus* in bambara groundnuts seeds treated with dry powder from leaves of *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii*, *L. javanica*, *C. dichogamus*, positive control (Actellic dust) and negative control. Among all treatments *T. vogelii* and actellic dust were the most effective treatments by killing 93.07 - 100% and 91.33 - 100% of bruchids respectively for 180 days of the study (Fig. 13). All treatments showed significant ($P \leq 0.001$) effect on bruchids mortality. The dead insects were recorded for both insects inside the bags and those killed on the surface of the bags. For *T. vogelii* and actellic dust, most of the dead insects were observed on the surface on the storage bags. Other pesticidal plants displayed varying bruchids mortality but not as higher as the mortality caused by Actellic Dust and *T. vogelii*. For all treatments, the number of dead increased with exposure time from 30 – 180 days.

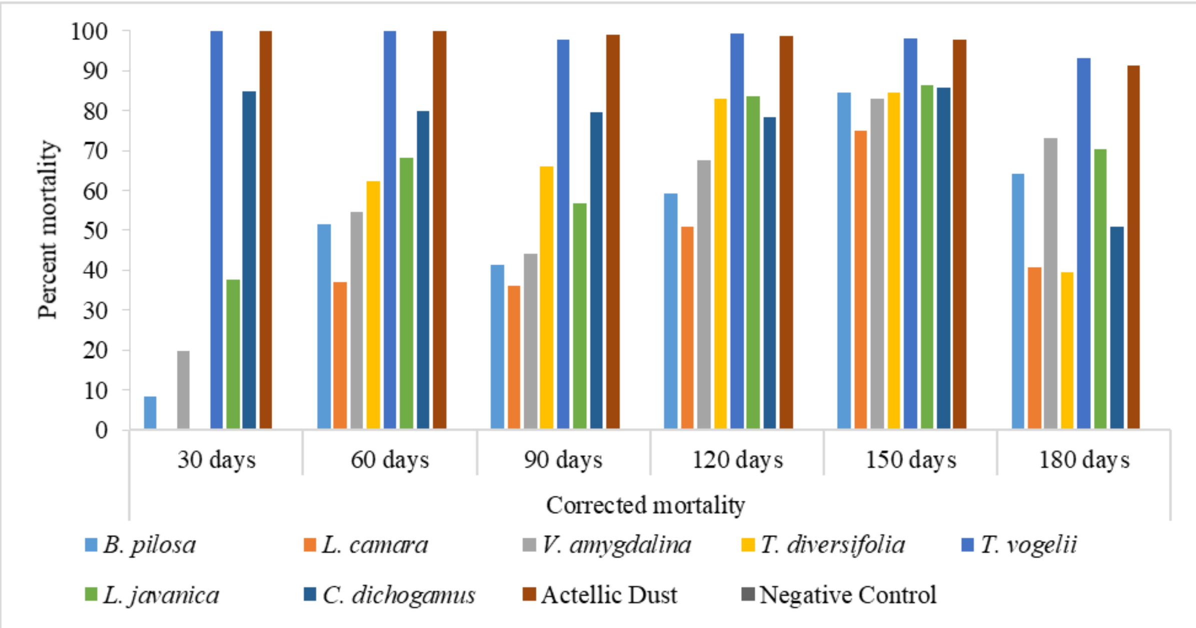


Figure 13: Percent corrected mortality of *C. maculatus*

Table 3: Mean number of dead insects (*C. maculatus*) in stored bambara groundnuts

Treatments	Mean ± SE of dead *C. maculatus*					
	30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
B. pilosa	0.17 ± 0.167b	5.50 ± 0.563bcd	13.17 ± 2.994c	61.00 ± 12.793dc	75.50 ± 18.366cd	63.1 ± 15.865cd
L. camara	0.00 ± 0.000b	2.83 ± 0.792de	10.67 ± 1.687c	44.67 ± 4.863d	54.67 ± 6.551d	45.17 ± 13.956de
V. amygdalina	0.33 ± 0.333b	6.00 ± 0.966abcd	14.33 ± 2.275bc	83.83 ± 13.260c	58.50 ± 8.217d	43.50 ± 11.644de
T. diversifolia	0.00 ± 0.000b	4.67 ± 1.745cd	13.67 ± 3.547c	54.33 ± 7.495dc	103.83 ± 8.256bc	93.67 ± 21.942c
T. vogelii	2.17 ± 0.307a	9.00 ± 1.291bc	22.17 ± 2.892ab	159.83 ± 9.134a	123.33 ± 8.019b	149.33 ± 16.760b
L. javanica	0.50 ± 0.342b	7.17 ± 1.376abc	16.83 ± 3.240bc	121.67 ± 11.604b	104.33 ± 11.485bc	77.50 ± 5.720cd
C. dichogamus	1.83 ± 0.980a	4.67 ± 0.803cd	15.33 ± 4.193bc	39.00 ± 5.882d	98.83 ± 10.291bc	93.17 ± 9.945c
Actellic Dust	2.29 ± 0.680a	9.29 ± 2.044a	29.71 ± 2.982a	186.00 ± 16.569a	201.71 ± 14.923a	213.86 ± 19.280a
Negative Control	0.00 ± 0.000b	0.00 ± 000e	0.43 ± 0.297d	8.29 ± 4.714e	4.14 ± 0.769e	8.71 ±1.960e
One-way ANOVA						
F-statistic	**4.94*** **	**5.94*** **	**8.66*** **	**33.47*** **	**28.22*** **	**20.06*** **

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) using Fisher's Least Significant Difference (LSD) test

4.1.7 Bambara groundnut grains damage by *C. maculatus*

The results of the treatment of the bambara groundnut seeds with the dry powder from *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii*, *L. javanica*, *C. dichogamus* and synthetic pesticide on the seeds damage is presented in Table 4. The results of this study showed that the treatment of the bambara groundnuts with pesticidal plants powder significantly protected the bambara groundnut seeds against damage by *C. maculatus* among treatments throughout the study period ($P \leq 0.001$). The highest damage was observed in the untreated bags (9.57 ± 2.125, 50.43 ± 9.149, 115.86 ± 9.290 and 286.14 ± 39.178, 419.86 ± 26.516 and 448.14 ± 20.249) for 30, 60, 90, 120, 150 and 180 days of assessment; respectively. The treatment with *T. vogelii* leaf powder and synthetic pesticide showed high effectiveness in protecting the bambara groundnut seeds damage by *C. maculatus* followed by *C. dichogamus* and *T. diversifolia*. Other pesticidal plants leaf powder, *L. javanica*, *B. pilosa*, *L. camara* and *V. amygdalina* showed relatively lower efficacy in protecting the bambara groundnut seeds against damage by *C. maculatus*. For all treatments, the damage increased with time from 30 - 180 days of storage. The increase in the number of seeds damaged from 30 - 180 days may be due to the increase of the live bruchids with time which is a result of degradation of active ingredients in pesticidal plants with time.

Table 4: Mean number of damaged bambara groundnut seeds

Treatment	Mean ± SE of damaged bambara groundnut					
	30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
B. pilosa	6.67 ± 2.140a	41.83 ± 2.496ab	86.17 ± 5.282b	248.50 ± 7.464ab	329.00 ± 17.047b	381.67 ± 17.990ab
L. camara	3.00± 1.033b	33.17 ± 5.388b	71.67 ± 8.349b	236.67 ± 13.111ab	292.83 ± 24.510b	381.83 ± 13.465ab
V. amygdalina	2.67 ± 0.989b	31.17 ± 1.887b	68.17 ± 8.491b	203.83 ± 14.646b	273.50 ± 8.962bc	344.83 ± 13.683b
T. diversifolia	1.33 ± 0.715b	11.33 ± 2.140cd	40.67 ± 3.648de	125.83 ± 6.544ef	204.00 ± 12.649d	272.83 ± 14.965cd
T. vogelii	0.00 ± 0.000b	0.00 ± 0.000d	0.00 ± 0.000g	1.17 ± 0.477g	5.50 ± 0.957f	10.50 ± 2.778f
L. javanica	1.83 ± 0.543b	15.50 ± 3.403c	51.00 ± 7.253de	173.00 ± 14.093de	215.83 ± 19.734cd	327.50 ± 24.930bc
C. dichogamus	0.50 ± 0.342b	2.17 ± 0.601d	24.00 ± 4.163ef	89.67 ± 14.523ef	155.83 ± 30.869d	252.67 ± 27.742d
Actellic dust	0.00 ± 0.000b	0.14 ± 0.143d	8.43 ± 5.639fg	46.14 ± 25.682fg	69.86 ± 29.278e	142.29 ± 44.029e
Negative Control	9.57 ± 2.125a	50.43 ± 9.149a	115.86 ± 9.290a	286.14 ± 39.178a	419.86 ± 26.516a	448.14 ± 20.249a
One-way ANOVA						
F-statistic	**7.94*** **	**21.26*** **	**34.85*** **	**23.92*** **	**36.15*** **	**32.60*** **

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher's Least Significant Difference (LSD) test

4.1.8 Oviposition of *C. maculatus* on bambara groundnut seeds

Treatment with pesticidal plants dry leaf powder showed varied effectiveness on oviposition of *C. maculatus* on the bambara groundnut seeds surface for 180 days of the study. The results showed that there was a significant difference ($P \leq 0.001$) in the number of bambara groundnut seeds with eggs on the surface throughout the study period. The highest number of seeds with eggs on the surface was observed in untreated seeds (54.00 ± 10.704, 91.86 ± 13.440, 152.86 ± 14.530, 215.14 ± 26.593, 69.43 ± 13.156 and 38.14 ± 9.130) for 30, 60, 90, 120, 150 and 180 days respectively (Table 5). The lowest number of seeds with eggs on the surface were observed on the seeds treated with *T. vogelii* and actellic dust. For the first 30 days of the storage *T. vogelii* and actellic dust completely prevented the oviposition of the *C. maculatus* on bambara groundnut seeds whereby, from the 90-180 day of assessment few seeds with eggs on the surface were observed on seeds treated with the *T. vogelii* and synthetic pesticide (actellic dust). The dry leaf powder from other pesticidal plants powder (*B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *L. javanica* and *C. dichogamus*) showed varied effectiveness in preventing the oviposition of *C. maculatus* on bambara groundnut seeds. There is generally decrease in number of seeds with the eggs on the surface from 150 - 180 days for bags treated with *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia, L. javanica* and *C. dichogamus* leaf powders.

Table 5: Mean number of bambara groundnut seeds with eggs on the surface

Treatment	Mean ± SE of bambara groundnut seeds with eggs					
	30 days	**60 days**	**90 days**	**120 days**	**150 days**	**180 days**
B. pilosa	12.17 ± 3.978b	55.33 ± 10.610b	97.17 ± 16.378b	177.50 ± 9.899ab	32.17 ± 13.922b	10.83 ± 2.286de
L. camara	10.17 ± 3.506b	31.00 ± 3.733c	59.67 ± 5.439c	146.33 ± 11.014bc	69.33 ± 6.243a	30.33 ± 6.917bcd
V. amygdalina	10.33 ± 2.333b	31.83 ± 3.516c	57.17 ± 6.720cd	136.17 ± 12.098c	39.00 ± 12.031b	15.00 ± 3.670cde
T. diversifolia	4.33 ± 1.453b	14.83 ± 4.785cde	34.33 ± 2.642de	76.67 ± 11.242d	39.17 ± 9.105b	37.50 ± 11.078bc
T. vogelii	0.00 ± 0.000b	0.00 ± 0.000e	0.17 ± 0.167f	1.17 ± 0.307e	2.00 ± 0.632c	5.00 ± 0.516e
L. javanica	9.33 ± 3.480b	23.83 ± 2.903cd	51.33 ± 7.455cde	121.83 ± 17.539c	19.17 ± 6.565bc	15.00 ± 6.197cde
C. dichogamus	3.33 ± 1.116b	8.33 ± 3.018de	30.67 ± 6.275e	69.00 ± 6.066d	73.83 ± 5.186a	63.17 ± 4.881a
Actellic Dust	0.00 ± 0.000b	0.29 ± 0.286e	3.43 ± 1.131f	8.71 ± 1.209e	14.14 ± 2.988bc	44.00 ± 15.424ab
Negative Control	54.00 ± 10.704a	91.86 ± 13.440a	152.86 ± 14.530a	215.14 ± 26.593a	69.43 ± 13.156a	38.14 ± 9.130bc
One-way ANOVA						
F-statistic	**14.12*** **	**21.12*** **	**31.85*** **	**29.59*** **	**8.58*** **	**4.86** **

; * significant at $P \leq 0.05$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher's Least Significant Difference (LSD) test

4.2 Discussion

4.2.1 Effectiveness of pesticidal plant extracts on field pests in bambara groundnuts.

The results of present study have showed that the leaf extracts of *B. pilosa, L. camara, V. amygdalina*, *T. diversifolia*, *T. vogelii* and *L. javanica* were effective against foliage beetles (*O. spp.*) (Coleoptera: Chrysomelidae), aphids (*Aphis spp*.) (Hemiptera: Aphididae), mealybugs (Hemiptera: Pseudococcidae), red spider mites (*Tetrunychus sp*. (Acari: Tetranychidae) and leafhoppers, (Homoptera: Cicadellidae) on bambara groundnuts. The pesticidal plants tested in this study exhibited pesticidal efficacy against all the tested insects. The insecticidal activity of the pesticidal plants is a result of the bioactive compounds that either deter feeding of the pests, kill the pests or respell pests from landing on plants for feeding or inhibit the insect's development (Belmain *et al.*, 2013; Isman, 2000). The findings of this study are in line with the findings from the previous studies (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018) with regard to the effectiveness of pesticidal plant extract against pests.

From the findings of the present study, it was revealed that *T. vogelii* was most effective among all the pesticidal plants evaluated. It highly reduced the abundance of arthropod pests and ultimately lowered the damage of the bambara groundnuts against field pests. The efficacy of *T. vogelii* against pests is a result of the presence of rotenoids which have been reported to have insecticidal properties (Belmain *et al.*, 2012; Mkindi *et al.*, 2019). The findings of this study is supported by the previous studies involving the use of extracts from *T. vogelii* foliar parts against foliage beetles (*O. mutabilis* and *O. bennigseni*), flower beetles (*Epicauta albovittata* and *E. limbatipennis*), aphids (*Aphis fabae*) and pod suckers (*Clavigralla tomentosicollis* and *C. hystricodes*) (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018).

Interestingly, the current study found that the extracts from *T. diversifolia* leaves showed pesticidal activity against foliage beetles, aphids, mealybugs, leafhoppers and red spider mites in the bambara groundnuts. The pesticidal activity of *T. diversifolia* leaf extracts is in partly explained by the presence of sesquiterpene lactones that have insecticidal properties (Green *et al.*, 2017). Previous research with regard to the use of extracts of *T. diversifolia* also reported the promising results against insect pests of common beans (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018). *Lantana camara* leaves extracts are rich in sesquiterpenes including α-humelene and cis-caryophyllene which have anti-insects properties (Sohani *et al.*, 2012).The results of this study showed that the extracts from *L. camara* was capable to reduce infestation of the arthropod pests on bambara groundnuts. The finding of the present study is in line with previous findings by (Mkindi *et al.*, 2017) when the leaf extracts were evaluated against the common bean insect pests. The pesticidal activity of *L. camara* is attributed by presence of bioactive compounds such as pentacyclic triterpenoids (Patel, 2011). The insecticidal activity of *V. amygdalina* is in part explained by presence of phytochemicals such as sesquiterpene lactones (vernodalinol and vernodalol) and flavonoids such as luteolin, luteolin 7-O-glucosides and luteolin 7-O-glucuronide, steroid glycosides, and vernonioside which were previously reported to have insect antifeedant, antitumoral, antifungal, and cytotoxic activity (Erasto *et al.*, 2006; Farombi & Owoeye, 2011; Green *et al.*, 2017). The results of the current study are supported by the previous research findings on the insecticidal property of the *V. amygdalina*. Furthermore, in the current study, *L. javanica* significantly reduced pest's abundance and hence the bambara groundnut plants damage. The insecticidal activity of *L. javanica* is in part explained by the presence of camphor and is also previously reported to have activity against insect pests (Mkenda *et al.*, 2015a). The fact that there was no infestation of red spider mites observed in plots treated with pesticidal plants including *L. javanica* provided proof that pesticidal plants contain diverse bioactive compounds that have acaricidal activity as previously reported in *L. javanica* (Madzimure *et al.*, 2011). *Bidens pilosa* is another pesticidal plant that has provided significant reduction in the pest's infestation on bambara groundnuts. *Bidens pilosa* contain sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene that might have attributed to the plants pesticidal potential.

With respect to beneficial arthropods, the current study revealed that pesticidal plants treatments have lower detrimental effect on beneficial arthropods; ladybird beetle (*Coccinella magnifica*) (Coleptera: Coccinellidea), hoverfly (Diptera: Syrphidae), wasps (Hymenoptera) and spiders (Araneae) as compared with synthetic pesticide. The higher abundance of beneficial arthropods observed in plots treated with pesticidal plants and untreated plots is explained partly by less threat of pesticidal plants extracts on non-target organisms (Mkindi *et al.*, 2017). On the other hand, a very lower abundance of beneficial arthropods was observed in plots treated with synthetic pesticide (positive control). This is in part due to the high lethal effect of synthetic pesticides and persistence unlike pesticidal plants (Ndakidemi *et al.*, 2016). Pesticidal plants pose low lethal effects due to the presence of less concentration of active ingredients (Desneux *et al.*, 2007). The active ingredients from pesticidal plants have a short life span in the environment and the soil as result over time they eventually lose their qualities such as odor, color, flavor and consistency (Miresmailli & Isman, 2014). Low persistence in the plants and soil after application makes it only effectively deter pests from feeding for shorter duration unlike synthetic pesticides which are highly persistent after application (Miresmailli & Isman, 2014). This even necessitates frequent application unlike synthetic pesticides. However, the lower persistence and lower lethal effect help the buildup of the population of natural enemies that also helps to provide the ecosystem services by feeding of the pests (Desneux *et al.*, 2007).

In terms of yield and yield components of bambara groundnuts, the findings of the present study showed a higher number of pods/plant in plots treated with *L. camara* leaf extracts and a higher number of seeds per pod in plots treated with *L. javanica* leaf extracts. The highest 100 seeds weight was observed in plots treated with *T. diversifolia* leaf extracts. There was no significant difference in terms of the pod and seed yield (kg/ha). Moreover, there was no significant difference in terms of the pod and seed yield (kg/ha). However, the higher pod yield and seeds yield (kg/ha) was observed in plots treated with *T. diversifolia* and *T. vogelii* leaf extracts. This could be explained in part by higher efficacy of the two plants in reducing the infestation of pests and hence lower plants damage and higher nitrogen content that might have provided additional nitrogen in form of foliar application (Jama *et al.*, 2000). The findings of this study are in line with the findings from studies by Mkindi *et al.* (2020). In their study, the extracts from *T. diversifolia* and *T. vogelii* were found to boost the chlorophll content and enhanced the growth and yield of the common beans. Contrary to expectations, the positive control (synthetic pesticide) had lower yield when compared with the pesticidal plant treatments and negative control. This might have been facilitated by heavy damage of the bambara groundnut plants due to the high infestation of red spider mites (*Tetrunychus sp*. (Acari: Tetranychidae) observed in plots treated with synthetic pesticide (karate). However, the yield obtained from this trial is generally lower than the average potential yield of 1 500–2 000 kg ha^{-1} (NARI, 2015). The lower average yield of the crop might be due to unfavorable climatic conditions including lower rains in the 2019 cropping season in Arusha, Tanzania which affected the yield of the crop.

4.2.2 Effectiveness of selected pesticidal plant leaf powders on the management of bruchids (*C. maculatus*) on bambara groundnuts

In this study, the effectiveness of *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii*, *L. javanica, C. dichogamus* and synthetic pesticide (actellic dust) were evaluated on *C. maculatus* live insects, mortality, bambara groundnut seeds damage (bruchids perforated seeds) and oviposition. The results of the study revealed the treatment of bambara groundnut seeds with dry powder from all pesticidal plant materials showed varied effectiveness as grain protectants against bruchids, *C. maculatus* infestation. The dry powder from the *T. vogelii* leaves was the most effective among all pesticidal plants evaluated displaying few live *C. maculatus*, high insect mortality, low oviposition and low grain damage. The treatment with *T. vogelii* completely protected the *C. maculatus* infestation for the first 90 days of the study. Despite the fact that its effectiveness slightly decreased after 90 days, however, it remained the most effective treatment against *C. maculatus*. The insecticidal activity of *T. vogelii* is in part explained by the presence diverse bioactive chemical compounds including Chemotype 1 (C1) which contains rotenoids with mammalian toxicity required for pest control (Belmain *et al.*, 2012; Stevenson *et al.*, 2012). The slight decrease in effectiveness after 90 days may be due to degradation of active ingredients over time. Other pesticidal plants *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *C. dichogamus* and *L. javanica* protected the bambara groundnut seeds against infestation and emergence of bruchids but was relatively less effective as compared with *T. vogelii* and positive control. This is indicated by the presence of a relatively higher number of live *C. maculatus*, high bruchids mortality, fewer seeds damage and lower oviposition in the bags in the bags treated with powder from the leaves *T. vogelii*. These findings are in line with the findings of the study conducted by Ogendo *et al.* (2003a) in which the *T. vogelii* leaf powder resulted to the mortality of maize weevil (*S. Zeamais*) in stored maize grain ranging from 85.0 – 93.7%. Their study showed that, the mortality of bruchids is proportional to the exposure time. Similar findings were obtained by Koona and Dorn (2005) when they investigated the potential of extracts from *T. vogelii* for the control of bruchids on stored legumes.

The results of the present study showed that *C. dichogamus* has insecticidal activity against *C. maculatus*. The treatment with the leaf powder from *C. dichogamus* displayed insect mortality, lower grain damage, few seeds with eggs on the surface and few live insects. The insecticidal property of *C. dichogamus* may be due to the presence of diverse toxic bioactive compounds such as crotofolane, diterpenoids, crotoxide A and B previously isolated from *C. dichogamus* leaves (Jogia *et al.*, 1989).

The insecticidal activity of *T. diversifolia* could be in part explained by presence of chemical compounds such as sesquiterpene lactones tagitinin A, tagitinin B, tagitinin C, tagitinin D and tagitinin H which have shown insecticidal activities against *C. maculatus* (Green *et al.*, 2017). *Lippia javanica* leaf powder on the other hand showed a significant effect on bruchids, grain damage, oviposition deterrent and bruchids mortality. The killing ability of *L. javanica* is attributed by chemical compounds such as camphor as the major component and other minor components such as camphene, α-pinene, eucalyptol, Z and E α-terpineol, linalool, cymene, thymol, 2-carene, caryophyllene and α-cubebene (Mkenda *et al.*, 2015b). The camphor a monoterpenoid is reported to have insecticidal potential (Chen *et al.*, 2018; Gillij *et al.*, 2008; Mkenda *et al.*, 2015b; Singh *et al.*, 2014; Tembo *et al.*, 2018). The findings of this study are in line with the findings of research by Chikukura *et al. (*2011) in which the leaf powders demonstrated insecticidal potential against storage insect pests of maize and cowpeas including *S. zeamais*, *C. maculatus*, *Prostephanus truncates, Tribolium spp* and *Sitotroga cerealella*.

Moreover, the treatment of bambara groundnut seeds with *V. amygdalina* leaf powder also resulted to lower the number of adult bruchids, lower seeds damage, lower oviposition and insect mortality as compared with the negative control. The insecticidal activity of the plant is attributed by presence of bioactive compounds such as sesquiterpene lactones including the vernolide and vernodalol (Erasto *et al.*, 2006; Igile *et al.*, 1994), flavonoids such as luteolin, luteolin 7-O-glucosides and luteolin 7-O-glucuronide, steroid glycosides, and vernonioside A, B, A1, A2, A3, B2, B3 and A4 (Farombi & Owoeye, 2011; Igile *et al.*, 1994). Several studies have reported the insecticidal potential of leaf powders of *V. amygdalina* against *C. maculatus* (*F.*) (Akunne *et al.*, 2014), beans weevil (*A. obtectus*) (Adeniyi *et al.*, 2010) and maize weevil (*S. zeamais*) (Asawalam & Hassanali, 2006).

The results showed that *L. camara* has a potential effect in protecting bambara groundnuts against *C. maculatus* damage. The treatment with the powder from *L. camara* leaves often showed a higher number of live insects, the number of seeds with eggs, low insect mortality and higher grains damage comparing with *T. vogelii* and positive control but performed better as compared with the negative control. The insecticidal activity of *L. camara* is influenced by the presence of pentacyclic triterpenoids (Durbesula *et al.*, 2015). The *L. camara* extracts are reported to have fumigant and contact toxicity against storage insects, *S. oryzae* (L.) *C. chinensis* (Fab.) and *Tribolium castaneum* (Herbst.) (Rajashekar *et al.*, 2014). Other studies by Ogendo *et al.* (2003a) revealed the insecticidal potential of leaf powder from *L. camara* against maize weevil. It was found that after 21 days, *L. camara* at the rate of 7.5-10% (w/v) resulted in 82.7% insect mortality.

Furthermore, the treatment with *B. pilosa* leaf powder displayed significant impact on protecting bambara groundnut against damage by *C. maculatus*. This is indicated by presence of relatively few live insects, low grain damage, low oviposition and high insect mortality as compared with untreated seeds. The insecticidal activity of *B. pilosa* might be explained in part by the presence of bioactive compounds such as sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene previously isolated from the flowers and leaves (Deba *et al.*, 2008; Lima Silva *et al.*, 2011). Previous studies by Goudoum *et al.* (2016) revealed the anti-insect function of the plant. It was found the essential oils from the leaves have insecticidal action against bruchids (*C. maculatus*). Renuka *et al.* (2014) investigated the essential oils from the leaves of *B. pilosa* investigated the methanol and acetone extracts of *B. pilosa* against stored pests of kidney beans, the *Z. subfasciatus* (Boheman) and *A. obtectus* (Say) (Coleoptera: Chrysomelidae). Both acetone and methanol extracts were found to cause 100% mortality of *A. obtectus* and *Z. subfasciatus.* For all treatments, there was continuous increase of the number of seeds damaged for all treatments from 30-120 days of the storage. However, *T. vogelii* leaf powder maintained its very high effectiveness throughout the study period. The increase of the damaged number of the bambara groundnut seeds was partly due to the increase in the number of live *C. maculatus* which may be due to degradation of the bioactive compounds in pesticidal plants over time. Additionally, the killing ability displayed by all pesticidal plants powders used this study could be partly explained by the presence of bioactive compounds aided by the action of fine powder blocking the insect spiracles resulting to death due to suffocation (Obembe & Kayode, 2013).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the findings of the present study showed that pesticidal plants are effective in controlling the field pests and the storage insect (*C. maculatus*) in bambara groundnuts. Under field conditions, it was found that the pesticidal plants extracts of *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* at the concentration of 10% (w/v) are effective for controlling the field pests including foliage beetles (*O. spp.*), aphids (*Aphis spp.*), mealybugs, red spider mites (*Tetrunychus sp.*) and leafhoppers. Interestingly, *T. vogelii* was the most effective pesticidal plants extracts against field pests and *C. maculatus* of bambara groundnuts among all pesticidal plants investigated. From the field experiment, it was found that the treatments with pesticidal plants (*B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii*, *L. javanica*) can control pests in the field without potential threat to the beneficial arthropods that can regulate the abundance of the pests. The treatment with pesticidal plants besides controlling pests and enhancing the abundance of beneficial arthropods, they also improved the yield of the bambara groundnuts. This indicates that the application of pesticidal plants specifically leguminous species (*T. vogelii*) and *T. diversifolia* (Asteraceae) supplements additional nutrients to the plants in the form of foliar applications. In a storage experiment, *T. vogelii* 10% (w/w) was the most effective among other pesticidal plants powder. This is indicated by their ability to reduce the infestation of bruchids, seeds damage (perforation), oviposition and cause higher insect mortality as compared with other pesticidal plants powders. This entails that, the pesticidal plants powder are effective grain protectant.

5.2 Recommendations

The findings of this study have indicated that pesticidal plants extracts are effective in controlling of bambara groundnuts pests in the field and post-harvest pests. Therefore, this study recommends:

(i) The use of *T. vogelii* extract for control field pests and dry leaf powder for control of storage insects in bambara groundnuts.

(ii) Future research to determine the level of toxicity on the non-target organism and possible health risks associated with the use of botanical pesticides including consumption of the crop produce protected by the use of pesticidal plants extract and powders.

(iii) The study suggests determining the shelf-life of the bioactive compounds in pesticidal plants under field conditions to optimize the proper application intervals without the pesticidal plants losing their quality to protect the crops against pests.

(iv) Future research to determine the amount of mineral nutrients added by foliar application of *T. diversifolia* and *T. vogelii*.

(v) Currently, most of these plants are harvested from the wild without proper sustainable replanting by the farmers. This study recommends developing strategies that promote the conservation of pesticidal plants which have shown high effectiveness for the sustainable availability of these plants.

(vi) The findings of this study revealed that plots treated with synthetic pesticides (and not other treatment) were infested by red spider mites contrary to expectations. Thus future research is recommended to evaluate the influence of the synthetic pesticide on red spider mite infestation.

REFERENCES

Abate, T., & Ampofo, J. K. O. (1996). Insect pests of beans in Africa: their ecology and management. *Annual Review of Entomology,* 41(1), 45-73.

Adeleke, O. R., Adiamo, O. Q., & Fawale, O. S. (2018). Nutritional, physicochemical, and functional properties of protein concentrate and isolate of newly-developed bambara groundnut (*Vigna subterrenea* L.) cultivars. *Food Ecience & Nutrition,* 6(1), 229-242.

Adeniyi, S., Orjiekwe, C., Ehiagbonare, J., & Arimah, B. (2010). Preliminary phytochemical analysis and insecticidal activity of ethanolic extracts of four tropical plants (*Vernonia amygdalina*, *Sida acuta*, *Ocimum gratissimum* and *Telfaria occidentalis*) against beans weevil (*Acanthscelides obtectus*). *International Journal of Physical Sciences,* 5(6), 753-762.

Ahmed, M., Mamun, M., Hoque, M., & Chowdhury, R. (2012). Influence of weather parameters on red spider mite-a major pest of tea in Bangladesh. *Journal of Science and Technology,* 19(5), 47-53.

Ajao, A., & Moteetee, A. (2017). *Tithonia diversifolia* (Hemsl) A. Gray. (Asteraceae: Heliantheae), an invasive plant of significant ethnopharmacological importance: A review. *South African Journal of Botany,* 113, 396-403.

Ajayi, F., & Lale, N. (2000). Susceptibility of unprotected seeds and seeds of local bambara groundnut cultivars protected with insecticidal essential oils to infestation by *Callosobruchus maculatus* (F.)(Coleoptera: Bruchidae). *Journal of Stored Products Research,* 37(1), 47-62.

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology,* 2(1), 1-12.

Akunne, C., Ononye, B., & Mogbo, T. (2014). Evaluation of the efficacy of mixed leaf powders of Vernonia amygdalina (L.) and *Azadirachta indica* (A. Juss) against *Callosobruchus maculatus* (F.)(Coleoptera: Bruchidae). *Advances in Bioscience and Bioengineering,* 1(2), 86-95.

Alara, O., Abdurahman, N., & Olalere, O. (2017). Ethanolic extraction of flavonoids, phenolics and antioxidants from *Vernonia amygdalina* leaf using two-level factorial design. *Journal of King Saud University-Science,* 32(1), 7-16.

Aldhaher, A., Langat, M., Ndunda, B., Chirchir, D., Midiwo, J. O., Njue, A., Schwikkard, S., Carew, M., & Mulholland, D. (2017). Diterpenoids from the roots of *Croton dichogamus* Pax. *Phytochemistry,* 144, 1-8.

Aliyu, M., Ladan, T., Ahmed, B., & Abdullahi, J. (2007). Studies on the efficacy of black soap and kerosene mixture on the control of Pod sucking bugs (*Clavigralla tomentosicollis* stal.) on Cowpea (*Vigna unguiculata* (L.) Walp). *Emirates Journal of Food and Agriculture*, 19(2), 8-14.

Anjarwalla P., Belmain S., Ofori D. A., Sola P., Jamnadass R., & Stevenson, P.C. (2016). *Handbook on pesticidal plants*. World Agroforestry Centre (ICRAF): Nairobi, Kenya.

Annan, I. B., Saxena, K., Schaefers, G., & Tingey, W. M. (1994). Effects of infestation by cowpea aphid (Homoptera: Aphididae) on different growth stages of resistant and susceptible cowpea cultivars. *International Journal of Tropical Insect Science,* 15(4-5), 401-410.

Arthur, G., Naidoo, K., & Coopoosamy, R. (2012). *Bidens pilosa* L.: Agricultural and pharmaceutical importance. *Journal of Medicinal Plants Research,* 6(17), 3282-3281.

Asawalam, E. F., & Dioka, U. J. (2012). Evaluation of toxicity of *Dennitia tripetala* baker f. and curcuma longa l. rhizomes against cowpea seed bruchid, *Callosobruchus maculatus* (F.) coleoptera: bruchidae. *Agricultural Science Research Journal,* 2(6), 308 – 311.

Asawalam, E. F., & Hassanali, A. (2006). Constituents of the essential oil of *Vernonia amygdalin*a as maize weevil protectants. *Tropical and Subtropical Agroecosystems,* 6 (2), 95-102.

Ashafa, A., & Afolayan, A. (2009). Screening the root extracts from B*iden pilosa* L. var. radiata (Asteraceae) for antimicrobial potentials. *Journal of Medicinal Plants Research,* 3(8), 568-572.

Atiku, A., Aviara, N., & Haque, M. (2004). Performance evaluation of a bambara ground nut sheller. *Agricultural Engineering International: CIGR Journal,* 6, 1-18.

Azam, A. S., Sesay, A., Karikari, S., Massawe, F., Manjarrez, A. J., Bannayan, M., & Hampson, K. (2001). Assessing the potential of an underutilized crop–a case study using bambara groundnut. *Experimental Agriculture,* 37(4), 433-472.

Bag, D. (2000). Pesticides and health risks. *Economic and Political Weekly*,35(38), 3381-3383.

Bagarama, F. (2016). Why is the red spider mite (*Tetranychus evansi*) a threat to dry season tomato growing in tabora, Tanzania. *Huria: Journal of the Open University of Tanzania*, 22(1), 1-10.

Baroacha, R. F., Ujjan, A. A., Khanzada, M. A., Manzur, A., & Shahzad, S. (2014). Efficacy of C*arica papaya* and *Aloe barbadensis* leaf extracts against mustard aphids (*Lipaphis erysimi* Kalt.). *International Journal of Biology and Biotechnology*, 11(1), 141-145.

Bartolome, A. P., Villaseñor, I. M., & Yang, W. C. (2013). *Bidens pilosa* L.(Asteraceae): botanical properties, traditional uses, phytochemistry and pharmacology. *Evidence-based Complementary and Alternative Medicine*, 2013 (340215), 1-52.

Baryeh, E. A. (2001). Physical properties of bambara groundnuts. *Journal of Food Engineering*, 47(4), 321-326.

Belmain, S., Haggar, J., Holt, J., & Stevenson, P. (2013). *Managing legume pests in sub-Saharan Africa: Challenges and prospects for improving food security and nutrition through agro ecological intensification*. Retrived from.https//gala.gre.ac.uk.id/eprint/12546

Belmain, S. R., Amoah, B. A., Nyirenda, S. P., Kamanula, J. F., & Stevenson, P. C. (2012). Highly variable insect control efficacy of *Tephrosia vogelii* chemotypes. *Journal of Agricultural and Food Chemistry*, 60(40), 10055-10063.

Bonsi, M., Osuji, P., Tuah, A., & Umunna, N. (1995). *Vernonia amygdalina* as a supplement to teff straw (*Eragrostis tef*) fed to Ethiopian Menz sheep. *Agroforestry Systems*, 31(3), 229-241.

Campolo, O., Giunti, G., Russo, A., Palmeri, V., & Zappalà, L. (2018). Essential oils in stored product insect pest control. *Journal of Food Quality*, 2018,1-18.

Castilhos, R., Grützmacher, A., & Coats, J. (2018). Acute toxicity and sublethal effects of terpenoids and essential oils on the predator *Chrysoperla externa* (Neuroptera: Chrysopidae). *Neotropical Entomology*, 47(2), 311-317.

Cenny, D., Bartolome, D., & Banwa, T. (2013). The potential of *Tithonia diversifolia* (Wild Sunflower) as organic foliar fertilizer. *European Scientific Journal*, 4, 465-468.

Chaubey, M. K. (2017). Study of insecticidal properties of garlic, *Allium sativum* (Alliaceae) and Bel, *Aegle marmelos* (Rutaceae) essential oils against *S. zeamais* L.(Coleoptera: Curculionidae). *Journal of Entomology,* 14, 191-198.

Chen, Z. Y., Guo, S. S., Cao, J. Q., Pang, X., Geng, Z. F., Wang, Y., … Du, S. S. (2018). Insecticidal and repellent activity of essential oil from *Amomum villosum* Lour. and its main compounds against two stored-product insects. *International Journal of Food Properties,* 21(1), 2265-2275.

Chikukura, L., Mvumi, B., Chikonzo, R., & Chenzara, C. (2011). Evaluation of selected indigenous pesticidal plant powders against stored maize and cowpeas insect pests. *African Crop Science Conference Proceeding*s, 10, 189-192.

Chougourou, D. C., Agossa, C. H., Zoclanclounon, Y. A. B., Nassara, M. G., & Agbaka, A. (2016). Efficacy of two plant powders as cowpea grain protectants against *Callosobruchus maculatus* Fabricius (Coleoptera, Chrysomelideae: Bruchinae). *Journal of Applied Biosciences,* 105(1), 10152-10156.

Clement, E., Erharuyi, O., Vincent, I., Joy, A., Christopher, A., Anthony, A., … Abiodun, F. (2014). Significance of bitter leaf (*Vernonia amagdalina*) in tropical diseases and beyond: A review. *Malaria Chemotherapy Control & Elimination,* 3(120), 1-10.

Collinson, S., Azam, A. S., Chavula, K., & Hodson, D. (1996). Growth, development and yield of bambara groundnut (Vigna subterranea) in response to soil moisture. *The Journal of Agricultural Science,* 126(3), 307-318.

Cooper, J., & Dobson, H. (2007). The benefits of pesticides to mankind and the environment. *Crop Protection,* 26(9), 1337-1348.

Dambolena, J. S., Zunino, M. P., Herrera, J. M., Pizzolitto, R. P., Areco, V. A., & Zygadlo, J. A. (2016). Terpenes: Natural products for controlling insects of importance to human Health—A structure-activity relationship study. *A Journal of Entomology,* 2016, 1-17.

Deba, F., Xuan, T. D., Yasuda, M., & Tawata, S. (2008). Chemical composition and antioxidant, antibacterial and antifungal activities of the essential oils from *Bidens pilosa* Linn. var. Radiata. *Food Control,* 19(4), 346-352.

Desneux, N., Decourtye, A., & Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology,* 52, 81-106.

Department of Agriculture, Fisheries and Forestry. (2016). *Bambara Groundnuts. Production Guideline*. Department of Agriculture, Fisheries and Forestry: Pretoria.

Dike, M. C. (1997). Effect of insect pests on pod and seed yields of bambara groundnut, *Vigna subterranea* L. Verde in Nigeria. *International Journal of Pest Management,* 43(3), 191-192.

Durbesula, A. T., Usham, G., & Kumar, R. (2015). Methemoglobinemia: Rare Presentation of Biofungicide Poisoning. *Journal of Dental and Medical Sciences,* 14(9), 10-14.

Dzenda, T., Ayo, J. O., Adelaiye., A. B & Adaudi, A.O. (2008). Ethnomedical and veterinary uses of *Tephrosia vogelii* Hook F (Fabaceae). *Australian Journal of Medical Herbalism*, 20(20), 71-80.

Emden, H. F., & Harrington, R. (2017). *Aphids as crop pests*. (2nd ed.) Cabi. Wallingford, Oxfordshire, UK.Retrived from https://lccn.loc.gov/2016042169

Endris, A., Asfaw, N., & Bisrat, D. (2016). Chemical composition, antimicrobial and antioxidant activities of the essential oil of *Lippia javanica* leaves from Ethiopia. *Journal of Essential Oil Research,* 28(3), 221-226.

Erasto, P., Grierson, D., & Afolayan, A. (2006). Bioactive sesquiterpene lactones from the leaves of Vernonia amygdalina. *Journal of Ethnopharmacology,* 106(1), 117-120.

Food and Agriculture Organization. (2018). *Statistic of production (FAOSTAT)*. Food and Agriculture Organization of the United Nations.

Farombi, E. O., & Owoeye, O. (2011). Antioxidative and chemopreventive properties of *Vernonia amygdalina* and *Garcinia biflavonoid*. *International Journal of Environmental Research and Public Health,* 8(6), 2533-2555.

Geissberger, P., & Séquin, U. (1991). Constituents of *Bidens pilosa* L.: Do the components found so far explain the use of this plant in traditional medicine. *Acta Tropica,* 48(4), 251-261.

Gertsch, J., Leonti, M., Raduner, S., Racz, I., Chen, J. Z., Xie, X. Q., … Zimmer, A. (2008). Beta-caryophyllene is a dietary cannabinoid. *Proceedings of the National Academy of Sciences,* 105(26), 9099-9104.

Gilden, R. C., Huffling, K., & Sattler, B. (2010). Pesticides and health risks. *Journal of Obstetric, Gynecologic & Neonatal Nursing,* 39(1), 103-110.

Gillij, Y., Gleiser, R., & Zygadlo, J. (2008). Mosquito repellent activity of essential oils of aromatic plants growing in Argentina. *Bioresource Technology,* 99(7), 2507-2515.

Goncalves, E., Herrera, I., Duarte, M., Bustamante, R. O., Lampo, M., Velasquez, G., … Rangel, G. S. (2014). Global invasion of *Lantana camara*: Has the climatic niche been conserved across continents. *PLoS One,* 9(10), 1-11.

Goudoum, A., Tinkeu, L. S. N., Mbofung, M. B. N., & Moses, C. (2016). Insecticidal and antifungal properties of essential oil of *Bidens pilosa* Linn. var. radita (Asteraceae) towards stored bambara groundnut insect and fungi pests. *Asian Journal of Agriculture and Food Sciences,* 4(02), 66-72.

Green, P. W., Belmain, S. R., Ndakidemi, P. A., Farrell, I. W., & Stevenson, P. C. (2017). Insecticidal activity of *Tithonia diversifolia* and *Vernonia amygdalina*. *Industrial Crops and Products,* 110 (2017), 15-21.

Grobbelaar, E. (2008). On the identity of *O. bennigseni* Weise, *O. mutabilis* (Schönherr) and *O. meridiana* sp. n.(Chrysomelidae: Galerucinae), bean and cowpea pests in the Afrotropical Region. *African Entomology,* 16(1), 7-23.

Halimi, R. A., Barkla, B., Mayes, S., & King, G. J. (2018). The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. *Journal of Food Composition and Analysis,* 77 (2018), 1-52.

Heller, J., Begemann, F., Mushonga, J. N. (1997). Bambara Groundnut (*Vigna Subterranea*) (L.) Verdc. Promoting the conservation and use of underutilized and neglected crops. P*roceedings of the workshop on conservation and improvement of bambara groundnut (Vigna Subterranea (L.) Verdc.)*. 14–16 November 1995, Harare, Zimbabwe.

Hernández, T., Canales, M., Avila, J., Duran, A., Caballero, J., Vivar, A. R., … Lira, R. (2003). Ethnobotany and antibacterial activity of some plants used in traditional medicine of Zapotitlán de las Salinas, Puebla (México). *Journal of Ethnopharmacology,* 88(2-3), 181-188.

Hill, D. S. (2008). *Pests of crops in warmer climates and their control*: Springer Science & Business.Media. doi: 10.1007/978-1-4020-6738-9

Hillocks, R., Bennett, C., & Mponda, O. (2012). Bambara nut: A review of utilisation, market potential and crop improvement. *African Crop Science Journal*, 20(1), 1-16.

Igile, G. O., Oleszek, W., Jurzysta, M., Burda, S., Fafunso, M., & Fasanmade, A. A. (1994). Flavonoids from *Vernonia amygdalina* and their antioxidant activities. *Journal of Agricultural and Food Chemistry,* 42(11), 2445-2448.

Ijeh, I. I., & Ejike, C. E. C. C. (2011). Current perspectives on the medicinal potentials of *Vernonia amygdalin*a Del. *Journal of Medicinal Plants Research,* 5(7), 1051-10161.

Isman, M. B. (2000). Plant essential oils for pest and disease management. *Crop Protection,* 19(8-10), 603-608.

Jama, B., Palm, C., Buresh, R., Niang, A., Gachengo, C., Nziguheba, G., … Amadalo, B. (2000). *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya. *Agroforestry Systems,* 49(2), 201-221.

Jogia, M. K., Andersen, R. J., Parkanyi, L., Clardy, J., Dublin, H. T., & Sinclair, A. (1989). Crotofolane diterpenoids from the African shrub *Croton dichogamus* Pax. *The Journal of Organic Chemistry,* 54(7), 1654-1657.

Kalita, S., Kumar, G., Karthik, L., & Rao, K. V. B. (2012). A Review on Medicinal Properties of *Lantana camara* Linn. *Research Journal of Pharmacy and Technology,* 5(6), 711.

Kisetu, E., Nyasasi, B., & Nyika, M. (2014). Effect of cropping systems on infestation and severity of field insect pests of cowpea in Morogoro, Tanzania. *Modern Research Journal of Agriculture,* 1(1), 1-9.

Koona, P., & Dorn, S. (2005). Extracts from *Tephrosia vogelii* for the protection of stored legume seeds against damage by three bruchid species. *Annals of Applied Biology,* 147(1), 43-48.

Kurade, N. P., Jaitak, V., Kaul, V. K., & Sharma, O. P. (2010). Chemical composition and antibacterial activity of essential oils of *Lantana camara*, *Ageratum houstonianum* and *Eupatorium adenophorum*. *Pharmaceutical Biology,* 48(5), 539-544.

Labeyrie, V. (2013). *The Ecology of Bruchids Attacking Legumes (Pulses*): *Proceedings of the International Symposium held at Tours (France)*, April 16–19, 1980 (1st ed). Springer Netherlands, Springer Science & Business Media. https://doi.org/10.1007/978-94-017-3286-4.

Lale, N., & Vidal, S. (2001). Intraspecific and interspecific competition in *Callosobruchus maculatus* (F.) and *Callosobruchus subinnotatus* (Pic) on stored bambara groundnut, *Vigna subterranea* (L.) Verdcourt. *Journal of Stored Products Research*, 37(4), 329-338.

Silva, F.L., Fischer, D. C. H., Tavares, J.F., Silva, M.S., Filho, P. F., Filho, B. J. M. (2011). Compilation of secondary metabolites from *Bidens pilosa* L. *Molecules*, 16(2011), 1070-1102.

Lozowicka, B., Kaczynski, P., Paritova, A., Kuzembekova, G., Abzhalieva, A., Sarsembayeva, N., … Alihan, K. (2014). Pesticide residues in grain from Kazakhstan and potential health risks associated with exposure to detected pesticides. *Food and Chemical Toxicology*, 64, 238-248.

Madzimure, J., Nyahangare, E. T., Hamudikuwanda, H., Hove, T., Stevenson, P. C., Belmain, S. R., … Mvumi, B. M. (2011). Acaricidal efficacy against cattle ticks and acute oral toxicity of *Lippia javanica* (Burm F.) Spreng. *Tropical Animal Health and Production,* 43(2), 481-489.

Magassouba, F., Diallo, A., Kouyaté, M., Mara, F., Mara, O., Bangoura, O., … Zaoro, M. (2007). Ethnobotanical survey and antibacterial activity of some plants used in Guinean traditional medicine. *Journal of Ethnopharmacology,* 114(1), 44-53.

Maina, Y., & Lale, N. (2004). Effects of initial infestation and interspecific competition on the developmentof *Callosobruchus subinnotat*us (Pic.) in bambara groundnut *Vigna subterranea* (L.) Verdcourt. *International Journal of Agriculture and Biology,* 6(6), 1059–1061.

Mamun, M., & Ahmed, M. (2011). Prospect of indigenous plant extracts in tea pest management. *International Journal of Agricultural Research, Innovation and Technology,* 1(1-2), 16-23.

Maroyi, A. (2017). *Lippia javanica* (Burm. f.) Spreng.: Traditional and commercial uses and phytochemical and pharmacological significance in the african and indian subcontinent. *Evidence-based Complementary and Alternative Medicine*, 2017*:*1-34.

Masaba, S. (2000). The antimalarial activity of *Vernonia amygdalina* Del (Compositae). *Transactions of the Royal Society of Tropical medicine and Hygiene*, 94(6): 694-695.

Massawe, F., Mwale, S., Azam, A. S., & Roberts, J. (2005). Breeding in bambara groundnut (*Vigna subterranea* (L.) Verdc.): Strategic considerations. *African Journal of Biotechnology,* 4(6), 463-471.

Mayes S., Ho W.K., Chai H.H., Song B., Chang Y., Massawe F. (2019). Bambara Groundnut (*Vigna Subterranea* (L) Verdc)—A climate smart crop for food and nutrition security. In: Kole C. (ed.) *Genomic Designing of Climate-Smart Pulse Crops*. (pp 397-424). Springer, Cham.

Minja, E., Zitsanza, E., Mviha, P., & Sohati, P. (1999). A note on host plants for the groundnut plant hopper, *Hilda patruelis*, in southern Africa. *Interim Advice Note*s, 19(1999), 35-36.

Miranda, M. A., Varela, R. M., Torres, A., Molinillo, J. M., Gualtieri, S. C., & Macías, F. A. (2015). Phytotoxins from *Tithonia diversifolia. Journal of Natural Products*, *78*(5), 1083-1092.

Miresmailli, S., & Isman, M. B. (2014). Botanical insecticides inspired by plant–herbivore chemical interactions. *Trends in Plant Science*, 19(1), 29-35.

Mkandawire, C. H. (2007). Review of bambara groundnut (*Vigna subterranea* (L.) Verdc.) production in Sub-Sahara Africa. *Agricultural Journal, 2*(4), 464-470.

Mkenda, P., Mwanauta, R., Stevenson, P. C., Ndakidemi, P., Mtei, K., & Belmain, S. R. (2015a). Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. *PloS One,* 10(11), 1-14.

Mkenda, P. A., Stevenson, P. C., Ndakidemi, P., Farman, D. I., & Belmain, S. R. (2015b). Contact and fumigant toxicity of five pesticidal plants against *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in stored cowpea (*Vigna unguiculata*). *International Journal of Tropical Insect Science,* 35(4), 172-184.

Mkindi, A., Mpumi, N., Tembo, Y., Stevenson, P. C., Ndakidemi, P. A., Mtei,… Belmain, S. R. (2017). Invasive weeds with pesticidal properties as potential new crops. *Industrial Crops and Products*, 110 (2017), 113-122.

Mkindi, A. G., Tembo, Y., Mbega, E. R., Medvecky, B., Smith, K. A., Farrell, I. W.,… Stevenson, P. C. (2019). Phytochemical analysis of *Tephrosia vogelii* across East Africa reveals three chemotypes that influence its use as a pesticidal plant. *Plants,* 8(12), 1-11.

Mkindi, A. G., Tembo, Y. L., Mbega, E. R., Smith, A. K., Farrell, I. W., Ndakidemi, P. A., … Belmain, S. R. (2020). Extracts of common pesticidal plants increase plant growth and yield in common bean plants. *Plants,* 9(2), 1-11.

Moronkola, D. O., Ogunwande, I. A., Walker, T. M., Setzer, W. N., & Oyewole, I. O. (2007). Identification of the main volatile compounds in the leaf and flower of *Tithonia diversifolia* (Hemsl) Gray. *Journal of Natural Medicines,* 61(1), 63-66.

Moyo, M., Nyakudya, I., Katsvanga, C., & Tafirei, R. (2006). Efficacy of the botanical pesticides, *Derris elliptica*, *Capsicum frutescens* and *Tagetes minut*a for the control of Brevicoryne brassicae in vegetables. *Journal of Sustainable Development in Africa,* 8(1), 216-222.

Mpotokwane, S., Gaditlhatlhelwe, E., Sebaka, A., & Jideani, V. (2008). Physical properties of bambara groundnuts from Botswana. *Journal of Food Engineering,* 89(1), 93-98.

Mpumi, N., Mtei, K., Machunda, R., & Ndakidemi, P. A. (2016). The toxicity, persistence and mode of actions of selected botanical pesticides in Africa against insect pests in common beans, *P. vulgaris*: A review. *American Journal of Plant Sciences,* 7(1), 138-151.

Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2018). Bambara groundnut (*Vigna subterranea* (L.) Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PloS One,* 13(10), 1-19.

Murevanhema, Y. Y., & Jideani, V. A. (2013). Potential of bambara groundnut (*Vigna subterranea* (L.) Verdc) milk as a probiotic beverage. *Critical Reviews in Food Science and Nutrition,* 53(9), 954-967.

Muthomi, J.W., Otieno, P.E., Ndetiru, J.H., & Wagacha, J.M., (2008). Effect of chemical spray on insect pests and yield quality of food grain legumes. *Journal of Entomology,* 5(3), 156-163.

Muzemu, S., Mvumi, B., Nyirenda, S., Sileshi, G., Sola, P., Chikukura, L., … Stevenson, P. (2011). Pesticidal effects of indigenous plants extracts against rape aphids and tomato red spider mites. *African Crop Science Conference Proceedings*, (10), 169 - 171.

Mwanauta, R. W., Mtei, K. A., & Ndakidemi, P. A. (2014). Prospective bioactive compounds from *Vernonia amygdalina*, *Lippia javanica*, *Dysphania ambrosioides* and *Tithonia diversifolia* in controlling legume insect pests. *Agricultural Sciences,* 5(12),1129-1139.

Naliendele Agricultural Research Institute. (2015). *Annual oil seeds and legume crops research report 2014/15*. Naliendele Agricultural Research Institute Annual Reports, 1-101.

Nasruddin, A., & Gassa, A. (2014). Field evaluation of several cultivated soybean varieties against *Empoasca terminalis* (Hemiptera: Cicadellidae). *Florida Entomologist,* 97(3): 995-1002.

Ndakidemi, B., Mtei, K., & Ndakidemi, P. A. (2016). Impacts of synthetic and botanical pesticides on beneficial insects. *Agricultural Sciences,* 7(06), 364-372.

Ntundu, W., Bach, I. C., Christiansen, J. L., & Andersen, S. B. (2004). Analysis of genetic diversity in bambara groundnut [*Vigna subterranea* (L.) Verdc] landraces using amplified fragment length polymorphism (AFLP) markers. *African Journal of Biotechnology,* 3(4), 220-225.

Obembe, O., & Kayode, J. (2013). Insecticidal activity of the aqueous extracts of four under-utilized tropical plants as protectant of cowpea seeds from *Callosobruchus maculatus* infestation. *Pakistan Journal of Biological Sciences,* 16(4), 175-179.

Ofuya, T. I. (1997). Control of the cowpea aphid, *Aphis craccivora* Koch (Homoptera: Aphididae), in cowpea, *Vigna unguiculata* (L.) Walp. *Integrated Pest Management reviews,* 2(4), 199-207.

Ogendo, J., Belmain, S., Deng, A., & Walker, D. (2003a). Comparison of toxic and repellent effects of *Lantana camara* L. with *Tephrosia vogelii* Hook and a synthetic pesticide against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in stored maize grain. *International Journal of Tropical Insect Science,* 23(2), 127-135.

Ogendo, J., Belmain, S., Deng, A. L., & Walker, D. (2003b). Efficacy of *Lantana camara* l. and *Tephrosia vogelii* Hook against *Sitophilus zeamai*s (Coleoptera: Curculionidae) in stored maize grains. *Acta Horticulture,* 5(679), 137-143.

Ojiako, F. O., Dialoke, S. A., Ihejirika, G. O., Ahuchaogu, C. E., & Ohiri, C. P. (2015). Comparative performance of pyrethrum [*Chrysanthemum cinerariifolium* Treviranus (Vis.)] extract and cypermethrin on some field insect pests of Groundnut (*Arachis hypogaea* L.) in Southeastern Nigeria. *American Journal of Experimental Agriculture,* 7(2), 96-106.

Osuga, I. M., Abdulrazak, S. A., Muleke, C. I., & Fujihara, T. (2012). Potential nutritive value of various parts of wild sunflower (*Tithonia diversifolia*) as source of feed for ruminants in Kenya. *Journal of Food, Agriculture & Environment,* 10(2), 632-635.

Pascual, M., Slowing, K., Carretero, E., Mata, D. S., & Villar, A. (2001). Lippia: Traditional uses, chemistry and pharmacology. *Journal of Ethnopharmacology,* 76(3), 201-214.

Patel, S. (2011). A weed with multiple utility: *Lantana camar*a. *Reviews in Environmental Science and Bio/Technology,* 10(4), 341–351.

Phoofolo, M., Mabaleha, S., & Mekbib, S. B. (2013). Laboratory assessment of insecticidal properties of *Tagetes minuta* crude extracts against *Brevicoryne brassicae* on cabbage. *Journal of Entomology and Nematology,* 5(6), 70-76.

Qwarse, M., Mihale, M. J., Joseph, S., Mugoyela, V., Henry, L., & Sunghwa, F. (2018). Ethnobotanical survey of medicinal and pesticidal plants used by agro-pastoral communities in Mbulu district, Tanzania. *Tanzania Journal of Science and Technology*, 1(1), 22- 35.

Rajashekar, Y., Ravindra, K., & Bakthavatsalam, N. (2014). Leaves of *Lantana camara* Linn.(Verbenaceae) as a potential insecticide for the management of three species of stored grain insect pests. *Journal of Food Science and Technology,* 51(11), 3494-3499.

Rao, G.V. R., Rameshwar Rao, V., & Ghaffar, M. (2013). *Handbook on groundnut insect pests identification and management*. Retrived from http://oar.icrisat.org/7041/

Raworth, D., Gillespie, D., Roy, M., & Thistlewood, H. (2001). *Tetranychus urticae* Koch, Twospotted Spider Mite (Acari: Tetranychidae) In P. G. Mason & J. T. Huber (Ed.), *Biological Control Programmes in Canada, 1981-2000* (pp. 259-265). New York: CABI Publishing.

Renuka, Thakur, D., & Sharma, R. (2014). Bioefficacy of *Bidens pilosa* L. against *Acanthoscelides obtectus* (Say) and *Zabrotes subfasciatus* (Boheman), stored pests of kidney beans, world wide. *International Journal of Agriculture and Crop Sciences,* 7(15), 1470-1477.

Rugumamu, C. P. (2014). Potency of traditional insecticide materials against stored bean weevil, *A. Obtectus* (Coleoptera: Bruchidae) in Tanzania. *Huria: Journal of the Open University of Tanzania,* 16, 126-139.

Salatino, A., Salatino, M. L. F., & Negri, G. (2007). Traditional uses, chemistry and pharmacology of Croton species (Euphorbiaceae). *Journal of the Brazilian Chemical Society*, 18(1), 11-33.

Shackleton, R. T., Witt, A. B., Aool, W., & Pratt, C. F. (2017). Distribution of the invasive alien weed, *Lantana camara*, and its ecological and livelihood impacts in eastern Africa. *African Journal of Range & Forage Science,* 34(1), 1-11.

Sharma, O. P., Sharma, S., Pattabhi, V., Mahato, S. B., & Sharma, P. D. (2007). A review of the hepatotoxic plant *Lantana camara*. *Critical Reviews in Toxicology*, 37(4), 313-352.

Singh, P., Jayaramaiah, R. H., Sarate, P., Thulasiram, H. V., Kulkarni, M. J., & Giri, A. P. (2014). Insecticidal potential of defense metabolites from *Ocimum kilimandscharicum* against Helicoverpa armigera. *PLoS One,* 9(8), 1-9.

Sohani, Z. N., Hojjati, M., & Barrachina, Á. A. C (2012). Bioactivity of *Lantana camara* L. essential oil against *Callosobruchus maculatus* (Fabricius). *Chilean Journal of Agricultural Research*, 72(4), 502.

Srinivasan, R. (2014). I*nsect and mite pests on vegetable legumes: a field guide for identification and management*: AVRDC-the World Vegetable Center. Retrived from https://worldveg.tind.io/record/52707/

Stevenson, P. C., Isman, M. B., & Belmain, S. R. (2017). Pesticidal plants in Africa: a global vision of new biological control products from local uses. *Industrial Crops and Products*, 110, 2-9.

Stevenson, P. C., Kite, G. C., Lewis, G. P., Forest, F., Nyirenda, S. P., Belmain, S. R., Sileshi, G. W., & Veitch, N. C. (2012). Distinct chemotypes of *Tephrosia vogelii* and implications for their use in pest control and soil enrichment. *Phytochemistry,* 78, 135-146.

Tagne, A. M., Marino, F., & Cosentino, M. (2018). *Tithonia diversifolia* (Hemsl.) A. Gray as a medicinal plant: A comprehensive review of its ethnopharmacology, phytochemistry, pharmacotoxicology and clinical relevance. *Journal of Ethnopharmacology*, 220, 94-116.

Tembo, Y., Mkindi, A. G., Mkenda, P. A., Mpumi, N., Mwanauta, R., Stevenson, P. C., Ndakidemi, P. A., & Belmain, S. R. (2018). Pesticidal plant extracts improve yield and reduce insect pests on legume crops without harming beneficial arthropods. *Frontiers in Plant Science*, 9, 1-10.

Temegne, N. C., Gouertoumbo, W. F., Wakem, G. A., Nkou, F. T. D., Youmbi, E., & Ntsefong, N. G. (2018). Origin and ecology of bambara groundnut (*Vigna Subterranea* (L.) Verdc: A Review. *Journal of Ecology & Natural Resources,* 2(4), 1-10.

Uddin, R., Azeez, K., & Lawal, A. (2017). Potentials of two bio-pesticides in the control of some field insect pests of bambara groundnut in Ilorin. *Ethiopian Journal of Environmental Studies and Management,* 10(4), 443-450.

Umar, A., & Turaki, J. M. (2014). Comparative studies on the Biology of C*allosobruchus maculatus* (F.) on soya beans and bambara groundnut. *Journal of Entomology and Zoology Studies,* 2(4), 58-61.

Wafula, M. C., Mutisya, M. D., & Malombe, I. (2019). Non-volatile chemical composition and botanical extracts from *Lippia javanica* (Burm. F) Spreng in Control of Cowpea Aphids. *Journal of Applied Sciences,* 19, 325-330.

Weinberger, K., & Srinivasan, R. (2009). Farmers' management of cabbage and cauliflower pests in India and their approaches to crop protection. *Journal of Asia-Pacific Entomology,* 12(4), 253-259.

William, A., Donkoh, S. A., & George, N. (2016). Adoption of bambara groundnut production and its effects on farmers' welfare in northern Ghana. *African Journal of Agricultural Research,* 11(7), 583-594.

World Health Organization (2016). *Test procedures for insecticide resistance monitoring in malaria vector mosquitoes* (2nd Ed,). World Health Organization: Geneva.

Xu, W. H., Liu, W. Y., & Liang, Q. (2018). Chemical constituents from *Croton* species and their biological activities. *Molecules,* 23(9), 2333.

Yang, F., Li, S., Chen, Y., Lao, S., Wang, Y., Dong, T. T., … Tsim, K. W. (2005). Identification and quantitation of eleven sesquiterpenes in three species of *Curcuma* rhizomes by pressurized liquid extraction and gas chromatography mass spectrometry. *Journal of Pharmaceutical and Biomedical Analysis,* 39(3-4), 552-558.

Yim, E. C., Kim, H. J., & Kim, S. J. (2014). Acute toxicity assessment of camphor in biopesticides by using *Daphnia magna* and *Danio rerio*. *Environmental Health and Toxicology,* 29,1-8.

Zhao, G., Li, X., Chen, W., Xi, Z., & Sun, L. (2012). Three new sesquiterpenes from *Tithonia diversifolia* and their anti-hyperglycemic activity. *Fitoterapia,* 83(8), 1590-1597.

Zoubiri, S., & Baaliouamer, A. (2012). Chemical composition and insecticidal properties of *Lantana camara* L. leaf essential oils from Algeria. *Journal of Essential Oil Research,* 24(4), 377-383.

APPENDICES

Appendix 1: Plot layout in RCBD

R-I	R-II	R-IV	R-V
BP	VA	TV	LJ
LC	KT	VA	BP
TV	TD	UT	KT
VA	BP	LC	TD
LJ	UT	KT	TV
TD	LC	LJ	UT
KT	TV	BP	VA
UT	LJ	TD	LC

KEY

R. I-IV: Replications

BP: *Bidens pilosa*

LC: *Lantana camara*

VA: *Vernonia amygdalina*

TV: *Tephrosia vogelii*

TD: *Tithonia diversifolia*

LJ: *Lippia javanica*

KT: Karate (Lambda-cyhalothrin)

UT: Untreated

Appendix 2: Arthropod pest abundance

Treatment	Mean number of arthropod pests				
	Foliage beetles	**Aphids**	**Spider mites**	**Mealybugs**	**Leafhoppers**
B. pilosa	0.11 ± 0.023bcd	0.47 ± 0.061b	0.00 ± 0.000b	0.08 ± 0.021bc	1.53 ±0.112b
L. camara	0.13 ± 0.029b	0.39 ± 0.055b	0.00 ± 0.000b	0.09 ± 0.023bc	1.69 ±0.119b
V. amygdalina	0.13 ± 0.028b	0.40 ± 0.054b	0.00 ± 0.000b	0.12 ± 0.027b	1.74 ± 0.123b
T. diversifolia	0.05 ± 0.015cde	0.18 ± 0.031c	0.00 ± 0.000b	0.05± 0.014c	1.01 ± 0.093c
T. vogelii	0.04 ± 0.012de	0.15 ± 0.030c	0.00 ± 0.000b	0.03 ± 0.013cd	1.13 ±0.098c
L. javanica	0.12 ± 0.025bc	0.34 ± 0.049b	0.00 ± 0.000b	0.12 ± 0.028b	1.54 ± 0.115b
Karate	0.02 ± 0.008e	0.00 ± 0.003d	0.60 ± 0.093a	0.01 ± 0.008d	0.14 ± 0.037d
Negative	0.38 ± 0.051a	0.92 ± 0.084a	0.00 ± 0.000b	0.24 ± 0.041a	2.51 ± 0.148a
One-way ANOVA					
F-statistic	**17.72*** **	**28.76*** **	**41.83*** **	**8.58*** **	**38.77*** **

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher's Least Significant Difference (LSD) test

Appendix 3: Beneficial arthropods abundance

Treatments	Mean number of beneficial arthropods			
	Lady bird beetle	**Hoverfly**	**Spiders**	**Wasps**
B. pilosa	0.19 ± 0.032b	0.29 ± 0.048a	0.15 ± 0.027a	0.13 ± 0.028b
L. camara	0.23 ± 0.043ab	0.35 ± 0.055a	0.18 ± 0.029a	0.11 ± 0.024ab
V. amygdalina	0.23 ± 0.049ab	0.33 ± 0.051a	0.16 ± 0.030a	0.11 ±0.025ab
T. diversifolia	0.28 ± 0.074ab	0.28 ± 0.044a	0.11 ± 0.022a	0.07 ±0.020bc
T. vogelii	0.24 ± 0.048ab	0.27 ± 0.047a	0.13 ± 0.024a	0.06 ± 0.016bc
L. javanica	0.28 ± 0.045ab	0.31 ± 0.050a	0.14 ± 0.023a	0.08 ± 0.021abc
Karate	0.04 ± 0.021c	0.09 ± 0.021b	0.02 ± 0.010b	0.05 ± 0.016c
Negative	0.33 ± 0.046a	0.39 ± 0.057a	0.14 ± 0.023a	0.12 ± 0.024ab
One-way ANOVA				
F-statistic	**3.37*** **	**3.46*** **	**3.65*** **	**2.00***

*; *** significant at $P \leq 0.05$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher's Least Significant Difference (LSD) test

Appendix 4: Pests incidence (%)

Treatment	Arthropod Pests incidence (%)				
	Foliage beetles	**Aphids**	**Spider mites**	**Mealybugs**	**Leafhoppers**
B. pilosa	8.33 ± 2.194bc	20.33 ± 3.062b	0.00 ± 0.000b	6.67 ± 1.882ab	44.67 ± 4.880abc
L. camara	9.00 ± 2.251b	18.00 ± 2.677bc	0.00 ± 0.000b	5.00 ± 1.689bc	47.33 ± 5.163ab
V. amygdalina	8.33 ± 2.343bc	17.67 ± 2.608bc	0.00 ± 0.000b	7.00 ± 2.169ab	49.00 ± 5.281a
T. diversifolia	4.33 ± 1.352bc	11.67 ± 2.088cd	0.00 ± 0.000b	4.00 ± 1.328bc	35.67 ± 4.174bc
T. vogelii	3.67 ± 1.385bc	10.00 ± 2.255d	0.00 ± 0.000b	2.33 ± 0.962bc	33.33 ± 4.502c
L. javanica	8.67 ± 2.145b	16.00 ± 2.506bcd	0.00 ± 0.000b	7.00 ± 2.007ab	46.00 ± 5.127abc
Karate	2.67 ± 1.111c	0.33 ± 0.333e	11.67 ± 4.179a	1.00 ± 0.567c	4.00 ± 1.488d
Negative	20.00 ± 3.428a	31.67 ± 3.722a	0.00 ± 0.000b	11.67 ± 3.055a	56.67 ± 5.667a
One-way ANOVA					
F-statistic	**6.42*****	**12.30*****	**7.79 *****	**3.19****	**11.83*****

; * significant at $P \leq 0.01$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) using Fisher's Least Significant Difference (LSD) test

Appendix 5: Plant damage

Treatment	Mean number of arthropod pests				
	Foliage beetles	**Aphids**	**Spider mites**	**Mealybugs**	**Leafhoppers**
B. pilosa	0.10 ± 0.019b	0.33 ± 0.044b	0.00 ± 0.000b	0.14 ± 0.068a	0.71 ± 0.050b
L. camara	0.10 ± 0.020b	0.26 ± 0.038bc	0.00 ± 0.000b	0.06 ± 0.015bc	0.78 ± 0.055b
V. amygdalina	0.09 ± 0.019b	0.30 ± 0.074bc	0.00 ± 0.000b	0.08 ± 0.019abc	0.80 ± 0.056b
T. diversifolia	0.04 ± 0.012dc	0.12 ± 0.020de	0.00 ± 0.000b	0.04 ± 0.011bc	0.48 ± 0.043c
T. vogelii	0.04 ± 0.011d	0.09 ± 0.017e	0.00 ± 0.000b	0.02 ± 0.009bc	0.49 ± 0.046c
L. javanica	0.10 ± 0.019b	0.21 ± 0.032cd	0.00 ± 0.000b	0.09 ± 0.019ab	0.73 ± 0.054b
Karate	0.02 ± 0.008d	0.00 ± 0.003e	0.51 ± 0.076a	0.01 ± 0.005c	0.04 ± 0.013d
Negative control	0.25 ± 0.032a	0.61 ± 0.059a	0.00 ± 0.000b	0.15 ± 0.025a	1.07 ± 0.064a
One-way ANOVA					
F-statistic	**14.58*** **	**19.87*** **	**45.13*** **	**3.26*** **	**37.41*** **

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) using Fisher's Least Significant Difference (LSD) test

Appendix 6: Yield and yield components of bambara groundnuts

Treatment	Yield components of bambara groundnuts				
	No. of pods/plant	No. of seeds/pod	100 seeds weight (gm)	Pod yield (kg/ha)	Seeds yield (kg/ha)
B. pilosa	14.50 ± 2.062ab	1.05 ± 0.020b	29.68 ± 4.496b	464.31 ± 107.848a	250.77 ± 65.888a
L. camara	16.25 ± 0.854a	1.10 ± 0.035ab	39.68 ± 3.713a	455.63 ± 54.497a	250.77 ± 36.938a
V. amygdalina	15.00 ± 1.225ab	1.07 ± 0.033b	38.50 ± 2.281ab	326.97 ± 13.254a	212.19 ± 19.290a
T. diversifolia	16.00 ± 1.291a	1.12 ± 0.022ab	39.90 ± 2.327a	493.25 ± 86.765a	289.35 ± 36.938a
T. vogelii	14.75 ± 1.315ab	1.06 ± 0.009b	36.85 ± 2.137ab	474.54 ± 62.199a	289.35 ± 36.938a
L. javanica	12.00 ± 1.581ab	1.17 ± 0.049a	28.85 ± 2.156b	472.03 ± 115.895a	250.77 ± 65.888a
Karate	13.25 ± 2.462ab	1.10 ± 0.019ab	32.83 ± 3.217ab	331.98 ± 116.695a	192.90 ± 66.823a
Negative	11.25 ± 1.377b	1.07 ± 0.013b	33.05 ± 5.312ab	383.49 ± 130.526a	231.48 ± 83.343a
One-way ANOVA					
F-statistic	**1.29***	**1.92***	**1.69***	**0.52ns**	**0.37ns**

*significant at $P \leq 0.05$ and ns means non-significant at $P \leq 0.05$. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher's Least Significant Difference (LSD) test